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Brand color tolerances: A Comparison of memory color vs. paired comparison color matching

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Brand Color Tolerances:

A Comparison of Memory Color vs. Paired Comparison Color Matching

By

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A thesis project submitted in partial fulfillment of the requirements for the degree of Master of Science in the School of Print Media in the College of Imaging Arts and Sciences of the Rochester Institute of Technology

August 2004

Thesis Advisor: Dr. Ed Granger

Permission granted

Brand Color Tolerances: A Comparison of Memory Color vs. Paired Comparison Color Matching.

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Abstract

The proposed thesis topic is to compare two methods of judging brand colors, paired comparison and memory color. Today's current practice for press approval in the graphic arts industry involves an individual using a sensitive comparison of a proof to a press sheet. The resulting piece is later viewed by a user who will have no knowledge of the original (a proof). The exception, however, is the memory of the "logo" or brand color that the user may have. The argument can be made that the additional cost of a press approval is justified by the possibility of accruing extra cost in the reprint of the piece if users do not find it acceptable. Determined in this study is the magnitude of the "memory" error in judging the printed color by comparing the "memory" error to the tolerance limits used by print buyers. The ratio of these two tolerances can be used to determine the waste in materials and time generated by the approval process.

Unlike the other research done on related topics, we will create our own "logo" color patches using the current methods of reproduction in the graphic arts industry. The ""s are used to denote that we have chosen color centers that do not represent any retail/commercial brand. Brand colors tend to be very saturated and will not allow for experimental exploration of plus/minus tolerance variations in the "logo" color.

Additionally, the experimental methods and viewing environment were designed to represent that of the graphic arts industry.

Chapter 1

Introduction

The printing industry spends a large amount of time and money trying to perfect color quality for their customers. An individual, typically a print buyer, using a sensitive comparison of a proof to a press sheet approves the print decision (paired comparison method). Print buyers demand high standards for their colors, more specifically their brand/logo colors, which may not be justifiable. When the end-user finally views the printed material they do not have an original to compare it to in order to know if the color is accurate (color memory method).

The purpose of this study is to determine if there is a significant difference between the tolerances of the two methods. A large difference would imply that the tight tolerances imposed in the current print buying practices are necessary. A larger acceptance of tolerance will have a large impact on possible savings in prepress and press cost. A small difference would imply that the current print buying practices are necessary and do reflect the behavior of an end user or their consumer.

If there is a large difference between the tolerances of paired comparison and color memory then the current practices could be wasteful in both materials and time. Several proofing iterations are required before the desired match is achieved between the designer's creation and the proof. There are then several hours or even days of press approval to match the proofs. Additionally, the current colorimetric tolerance is suspected to be many times more sensitive in detecting color differences than the tolerance developed from memory of the color. Therefore, the allowable tolerance for logo colors needs to be established relative to the current practices.

Chapter 2

Theoretical Basis of Study

Psychophysics

The experience of recognizing a change in stimulation is studied in the area of psychophysics. Psychophysics is the study of our ability to recognize a change in any sensation, visual, audio, etc. It is important to know how much change is necessary in order for humans to recognize a difference in these sensations to better understand the end users experience and meet their expectations. Gerscheider (1985) defines a stimulus or absolute threshold as changing the stimulus energy just enough to produce a sensation. The difference threshold is a measure of the change in a stimulus to produce a sensation of a just noticeable difference (JND). These sensations can differ by intensity, quality, extension, and duration (p. 1). The observer examines two stimuli and is asked which produces a different sensation. One of the stimuli has a fixed value and is referred to as the standard stimulus. The other stimulus is varied from trial to trial and is referred to as the comparison stimulus. It is common for there to be five, seven, or nine-comparison stimulus equally separated for an experiment (p. 42). Depending on the experiment, the stimuli are presented simultaneously or successively. However, in the successive technique time error or delay may be an issue. With a successive experiment the observer has to use the memory of the first image to use as a comparison for the second stimulus. The memory image may fade between the first stimulus and the second stimulus and so on. However, one possible way to prevent a time error is to present the standard stimuli at the first half of the trial and then again at the second half, depending on the amount of stimuli (p. 43).

A forced choice procedure is a method of measuring the observer's sensitivity. This procedure consists of two or more observation intervals by the participant in which they are asked to decide which observation contained a signal. Typically the observer will choose the interval with the largest sensory observation (p. 116).

Psychological: Consumers point of view

When developing consumer products corporate executives most important concern is what will get the customer to buy or not buy their product. According to Judd and Wyszecki (1975) consumers decide what to buy based on all the senses (touch, taste, smell, lift, and look). Using the sense of sight the customer perceives the color as belonging to the product, which is referred to as an object color (p.32). Whether the consumer is conscious of this or not they carry the memory of the perceived color with them to make decisions or comparisons as needed. Due to this, packaging of products must show the background and trademark colors, which the consumer will recognize. These colors are considered critical to the company. In the corporate world it is perceived that the differences in a color cause a bad impression to the customer. For example, if the color is lighter than the original this may suggest the product has been sitting around, which may lead the consumer to believe that the product is old or spoiled. Also if the color is too dark or gray this may send a message of dirt or excessive handling. These color characteristics are thought to inhibit a customer from purchasing a product. It is important to recognize there are many influences on the perception of a color. The most important are lighting, surrounding colors, or previously viewed colors (p.33). The following are an example of the considerations taken for viewing: the kind of lighting the product will be viewed under, the distance it will be viewed from, and the surrounding objects around the product (p.35).

Hyper-Graeco-Latin Squares

When developing any research methods it is important to avoid biased or uneven sampling and results. Hyper-Graeco-Latin Squares are used to produce an efficient sampling plan so that the individual judges have a reasonable number of judgments per test session. Latin squares help design an experiment to be appropriately randomized. This method samples three independent dimensions to produce 5 samples. The five samples from each dimension can then be added together. Please refer to the methods section for the sampling plan for this research experiment (Box, Hunter, & Hunter, 1978).

Chapter 3

Literature Review

Simultaneous vs. Successive color matching

Simultaneous (paired comparison) color matching is the comparison of two juxtaposed color samples with zero time delay. This method is based on perception with no use of memory. Additionally with this method observers have little difficulty in color discrimination (Capilla, Carpinelli, Fez, Lunque, & Pozo, 2001).

Successive (color memory) color matching occurs when there is a delay in time between viewing of the reference and the match. The decision of the match is made with no color reference under the same or different viewing conditions. The observer must use their memory to make a decision. From previous research we know some people have excellent color memory and others do not (Capilla, Carpinelli, Fez, Lunque, & Pozo, 2001).

In the area of simultaneous and successive color matching research has been done on the effect of time on memory matching, a comparison of the two methods and the effect different illuminants have on memory matching. All of theses studies used Munsell chips and paint chips with varied amounts of observers.

Two studies compared the method of simultaneous and successive color matching, but a very different procedure is proposed in this research. The first study used an apparatus that had two fields for color. For the simultaneous experiment half was filled with the test color and the observer adjusted the other half until they saw a match. In the successive experiment the field was completely filled with the test color and then replaced with the adjustable comparison color. Again the observer was asked to adjust until they saw a match. The time delay for this experiment was 5 seconds. The results from these experiments found successive matching was more variable, but was much quicker. Additionally, more purity and luminance would be needed to make accurate color matches based on color memory (Burnham, Clark, Newhall, 1975).

The second study comparing simultaneous and successive color matching used an apparatus of a bipartite circular field where each half could have a different stimulus produced by beams of light controlled by a shutter. Two observers participated in both experiments. In the successive experiment, the stimulus was shown for either 1 or 8 seconds followed by an interval of no stimulus. They were then shown the next stimulus and asked to decide if it was a match to the previous stimulus. For the simultaneous experiment the user was to decide if the two adjacent colors were a match. The results from this study also showed that there is less accuracy in the ability to discriminate among color successively than simultaneously (Barco, Hita, Romero, 1986).

For the study on the effect of time on memory matching the reference test instrument was a gray cardboard circle panel with paint chips placed on the outer edge. Both experiments used 20 comparison colors from the Munsell Book of Color varying in hue, value, and chroma. One hundred observers were selected with normal color vision to take part in the experiments. For the simultaneous experiment, the reference test was shown with the color chips and the observer was asked to pick out the chips that matched. The result was the correct color was almost always chosen. For the successive experiment, the observer was shown the reference test for 10 seconds followed by a time delay of either 15 seconds, 15 minutes, or 24 hours. After the time delay the observer was asked to pick a match from the comparison chips. The results showed the observer was more inclined to pick a lighter and higher chroma color. Additionally, they found that, as time increased there was greater variability in color memory (Baldovi, Castro, Fez, & Perez-Capinelli, 1998).

The last study was on the effect of different illuminants on color memory matching. The experiment used a Macbeth Cabinet, which was split in half with two different illuminants, D65 and A. Test colors were picked from the Munsell chips varying in hue, chroma, and value. Ten observers with normal color vision took part in both experiments. The successive experiment consisted of the observer first viewing the test color under D65 illumination for 10 seconds. Then after a 10-minute time delay the observer was given Munsell charts under illuminant A and asked to find a match. The simultaneous experiment asks the observer to view test and matching samples under different illuminants. The reference test was viewed under D65 and the four comparison charts viewed under illuminant A. The observers were asked to select a color match from the comparison charts. The results did not prove whether different illuminants had an effect or that it helped with constancy (Capilla, Capinelli, Fez, Lunque, & Pozo, 2001).

Chapter 4

Hypothesis

There are two hypotheses for this research. The first hypothesis is the tolerance for color memory color matching of brand colors used by the average user is larger than the paired comparison color matching of brand colors used by the print buyer. The second hypothesis is the tolerance for color memory color matching system is equal to or smaller than the paired comparison color matching of brand colors used by the print buyer.

Chapter 5

Methodology

Introduction

Brand color tolerances will be determined by judging five "logo" colors distributed around the color spectrum; blue, cyan, green, yellow, and red. Each of the five samples created will vary in five steps of hue, saturation, and lightness. Two experiments will be administered to each judge, color memory and paired comparison color matching to compare the color matching tolerances of the end user and the print buyer. The judge's estimation of match will be used to develop the response surface for both color memory and paired comparison. The response surface differences are then used to determine the number of paired comparison JND's (print buyer) that lie within the one (1.0) JND range of the memory colors. The number of print buyer (paired comparison) JND's that lie within the first JND of color memory judgment will give a measure of how many current iterations to final print quality are not required for saleable brand color. Using Thurstons Method we determined 1 sigma was equal to a z-score of approximately 0.85 being the upper limit 1 JND, 2 sigma equal to a z-score of approximately 1.29 being the upper limit for 2 JND's, and 3 sigma to equal a z-score of approximately 2.33 being the upper limit for 3 JND's.

Brand Color Creation

The “logo” samples were created in Adobe Photoshop 7.0 in a CMYK set to SWOP standards. Sets of 25 color patches for each “logo” (5x5x5 matrix) were created to use in the test experiment. For each “logo” (red, green, blue, cyan, yellow) a 5 x 5 x 5 matrix was created. Each patch in the matrix will vary in increments of hue, saturation, and lightness. And the combination of these increments is determined by using the hyper-graeco-latin squares sampling method. Once the matrixes were created the color patches were printed on the Kodak Approval Proofing System. This proofing system was chosen based on its overall color quality stability and popularity of use in the graphic arts industry for color proofing.

Figures 1-3 show the distribution of color patches for the test experiments. The third sample shown in each graph is the “logo” color. Samples 2 and 4 are the CIE delta E steps that are determined to give sensitive results for the paired comparison studies. Samples 1 and 5 are the steps determined for the successive or memory color experiment.

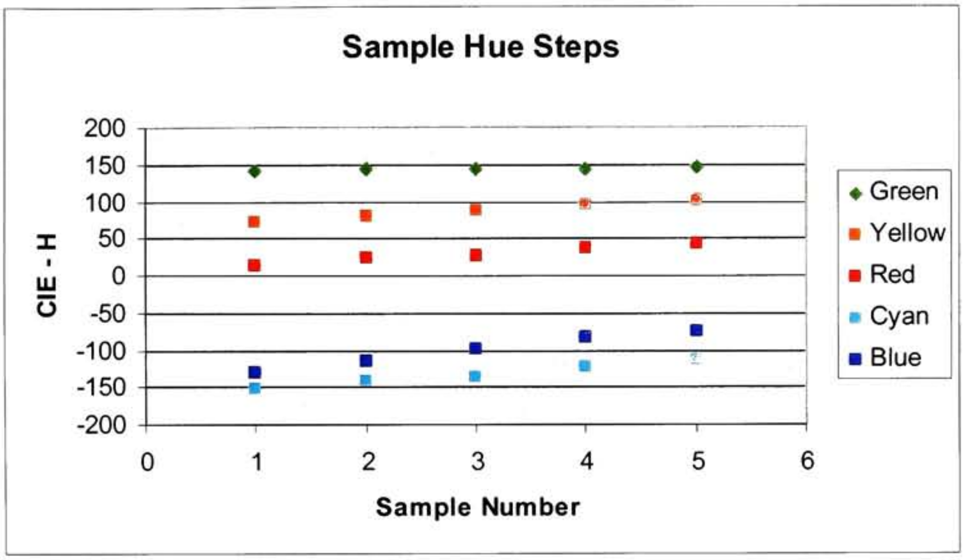


Figure 5.1: Hue Distribution

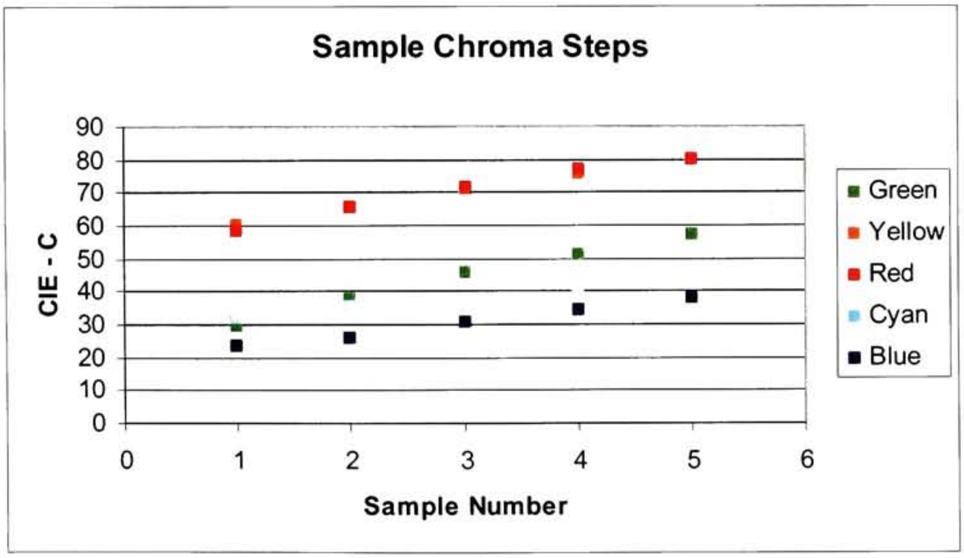


Figure 5.2: Chroma Distribution

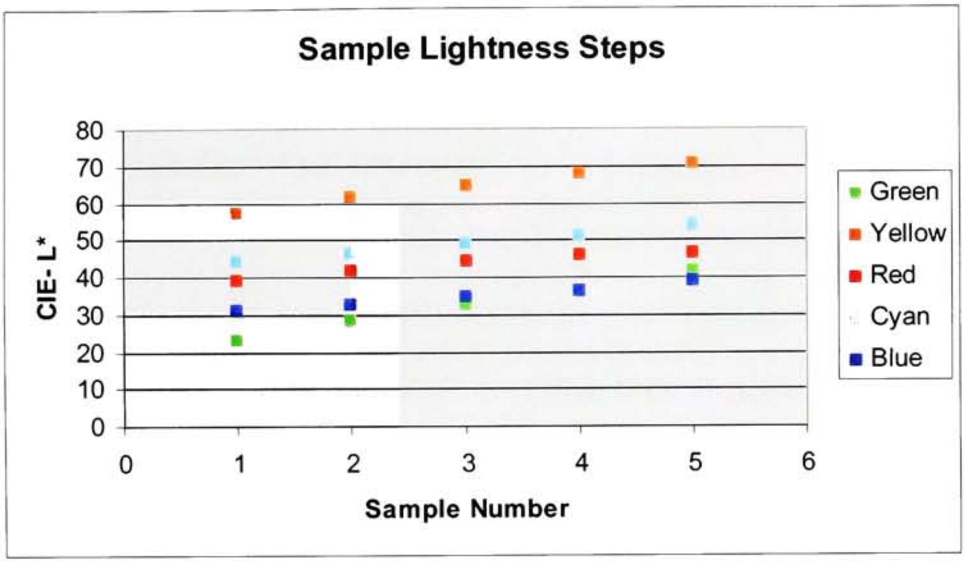


Figure 5.3: Lightness Distribution

Test Procedure

Once the test patches were created 20 students were selected from within the School of Print Media at the Rochester Institute of Technology to judge the acceptability of the color. For each "logo" color the student completed a color memory and a paired comparison color matching experiment. Both of these experiments took place within the Color Management Systems Lab using a D50 light booth. The color memory experiment was given first. The student were given a minute to view the "logo" color. It was then taken away for one minute. Next 25 varying patches of the "logo" color (including the logo color first shown) were given individually to the student. The student was asked to judge whether or not it was an acceptable representation of the "logo" color first shown. The answers were recorded and documented. This was repeated for the other 4 "logo" colors. After the color memory experiment the student was given the paired comparison experiment. For this experiment the student was allowed to keep the "logo" color while they were given the other 24 varying patches. Again the observers were asked to judge whether or not the patch is an acceptable representation of the "logo" color first shown. The answers were recorded and documented. This was repeated for the other 4 "logo" colors.

In addition to the subjective analysis, the final patches were measured in XYZ for conversions to CIE Lab. This data was compared to the subjective results of the experiment.

Sampling Plan

Hyper-Graeco-Latin Squares are used to produce an efficient sampling plan so that the individual judges have a reasonable number of judgments per test session. The sampling plan for this experiment uses five levels of lightness, hue, and saturation from each "logo" color. The lightness levels are denoted L1, L2, L3, L4, and L5; the hue levels, H1, H2, H3, H4, and H5 and the saturation levels, S1, S2, S3, S4, and S5. The test will be made for each of the five "logo" colors, denoted G1, G2, G3, G4, and G5. The first extended Latin square shown below is the order of the "logo" color to be judged by a 10-member panel. There are five of these hyper plane sets; the set to use is determined by the "logo" color number. The samples to be used in the judgment are determined by the row and column location of the observer "logo" color extended Latin square. For example, the first judge's initial selection is "logo" color number 1 in the first row and column of the observer "logo" grid.

	1
J1	1

Table 5.1: First selection for Judge #1

The patch to be judged also comes from the first row and column of the Hyper-Graeco-Latin Square for that color. In this case a patch would have chosen that has a maximum negative hue error, maximum positive saturation and lightness error.

	1
L1	1

	1
H1	1

	1
S1	1

Table 5.2: Lightness, Hue, & Saturation values for Patch #1

		Judge Number								
	1	2	3	4	5	6	7	8	9	10
G1	1	2	3	4	5	1	2	3	4	5
G2	2	3	4	5	1	2	3	4	5	1
G3	3	4	5	1	2	3	4	5	1	2
G4	4	5	1	2	3	4	5	1	2	3
G5	5	1	2	3	4	5	1	2	3	4

Table 5.3: Judge – "Logo" Color Extended Latin Square

		Judge Number								
	1	2	3	4	5	6	7	8	9	10
L1	1	2	3	4	5	1	2	3	4	5
L2	2	3	4	5	1	2	3	4	5	1
L3	3	4	5	1	2	3	4	5	1	2
L4	4	5	1	2	3	4	5	1	2	3
L5	5	1	2	3	4	5	1	2	3	4

Table 5.4: Lightness plane of the Hyper-Graeco-Latin Square

	Judge Number									
	1	2	3	4	5	6	7	8	9	10
H1	1	2	3	4	5	1	2	3	4	5
H2	2	3	4	5	1	2	3	4	5	1
H3	3	4	5	1	2	3	4	5	1	2
H4	4	5	1	2	3	4	5	1	2	3
H5	5	1	2	3	4	5	1	2	3	4

Table 5.5: Hue plane of the Hyper-Graeco-Latin Square

	Judge Number									
	1	2	3	4	5	6	7	8	9	10
S1	1	2	3	4	5	1	2	3	4	5
S2	2	3	4	5	1	2	3	4	5	1
S3	3	4	5	1	2	3	4	5	1	2
S4	4	5	1	2	3	4	5	1	2	3
S5	5	1	2	3	4	5	1	2	3	4

Table 5.6: Saturation Plane of the Hyper-Graeco-Latin Square

Once the testing was completed the data was entered into an excel spread sheet and put through comparative analysis with the CIE Lab readings of each color patch. As stated earlier the z-score was calculated for each patch and then used to determine the tolerance limits for the JND's. The results can be found in the next chapter, Chapter 6.

Chapter 6

Results

Introduction

As a result of these experiments we were able to start defining color tolerances for color matching in the graphic arts industry. To find the color tolerances we first used the paired comparison data to establish the JND (just noticeable difference) scales for hue, saturation, and lightness. By using a forced choice method the judges were asked to estimate the distance between the "logo" color and the test patch. In paired comparison we found limited capabilities when the differences in stimuli are large which caused the judges to always choose the distant color patches. We then found the overlapping data between the usable paired comparison data and the distance estimates made by the judges in order to translate the distance estimates to terms of JND's. Thurston's Law of Comparative Judgment was used to analyze the results of the paired comparison and memory color experiment and to convert the data into an interval z-score. Crossing the scales using common color patches compares the JND's from both experiments. The ratio of the JND scales is a measure of the degree of loss in productivity in the print buying process compared to using the color memory process.

Paired Comparison Study

The results of the paired comparison scaling are shown on the next few graphs. The data for all graphs is displayed for all the "logo" colors as a function of hue. Each graph illustrates the boundary for discrimination limits of one, two, and three JND's. The ordinal axis is chosen to be hue because we found hue to be the most critical factor in determining a match. This yields a nearly one-dimensional measure of the discrimination limits for lightness and chroma. As the graphs show, each judge tolerated a relatively large variation in chroma and lightness as long as the color test patch had the same hue angle as the "logo" color. This illustrates the importance of hue in making a color match.

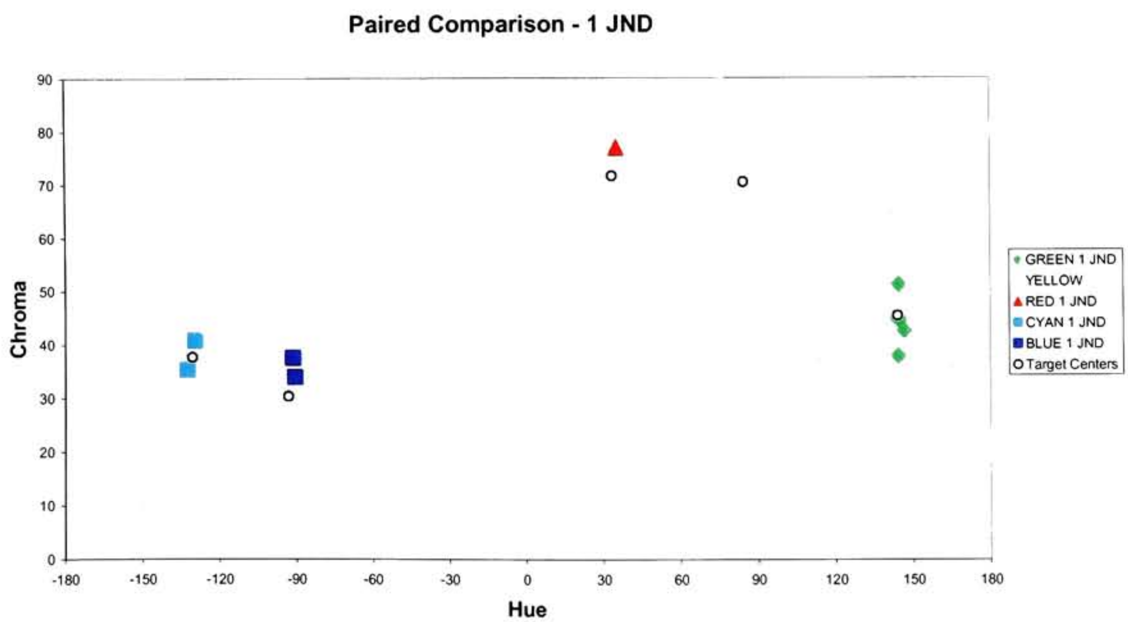


Figure 6.1: Paired Comparison Chroma vs. Hue 1 JND Discrimination Limit

In Figure 6.1 above, we can see that patches in 1 JND vary only in chroma with only a slight variation in hue, if any at all. In the graph below, figure 6.2, we can see that there is still only a slight variation in hue axis (more than the 1 JND data) with most of the variation in the chroma axis for 2 JND.

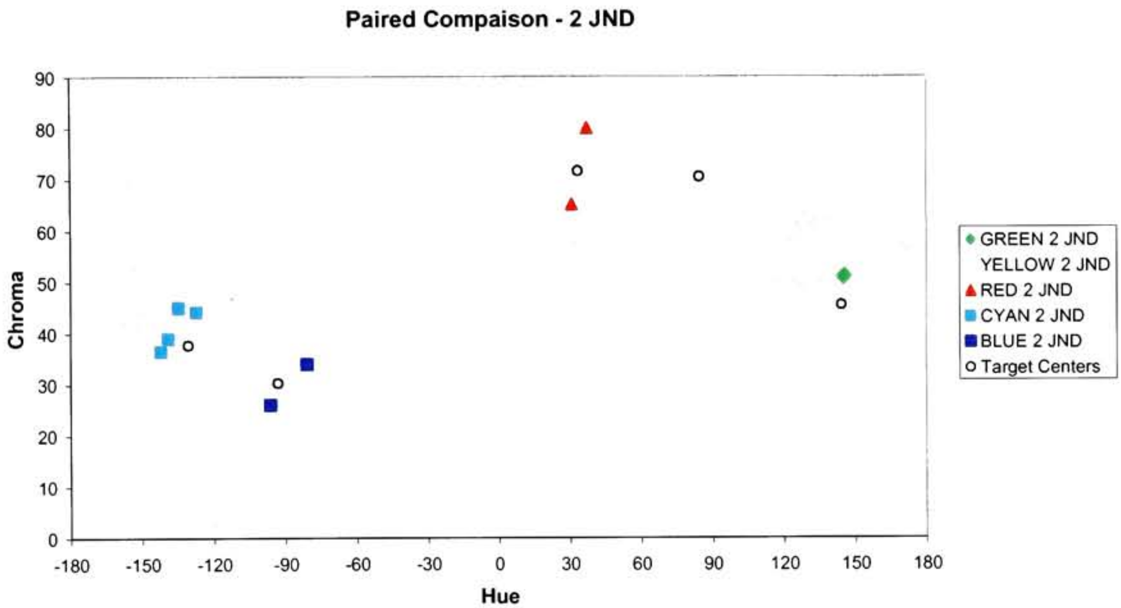


Figure 6.2: Paired Comparison Chroma vs. Hue 2 JND Discrimination Limit

Figure 6.3 on the next page, illustrates that a larger change in hue creates a more noticeable difference. Notice that now the patches vary much more in hue and with still variation in chroma.

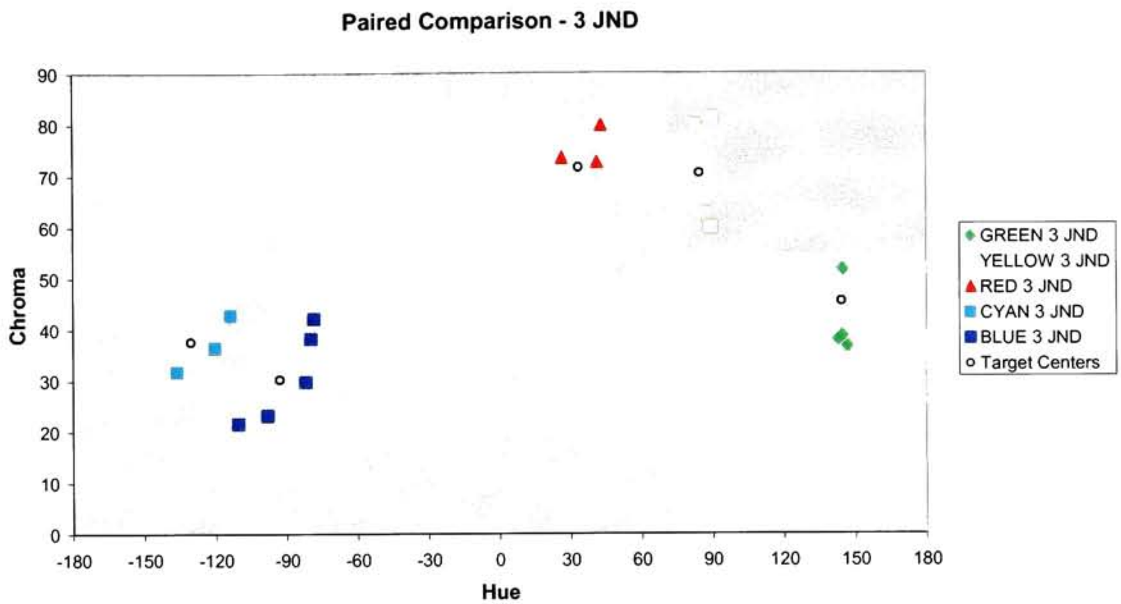


Figure 6.3: Paired Comparison Chroma vs. Hue 3 JND Discrimination Limit

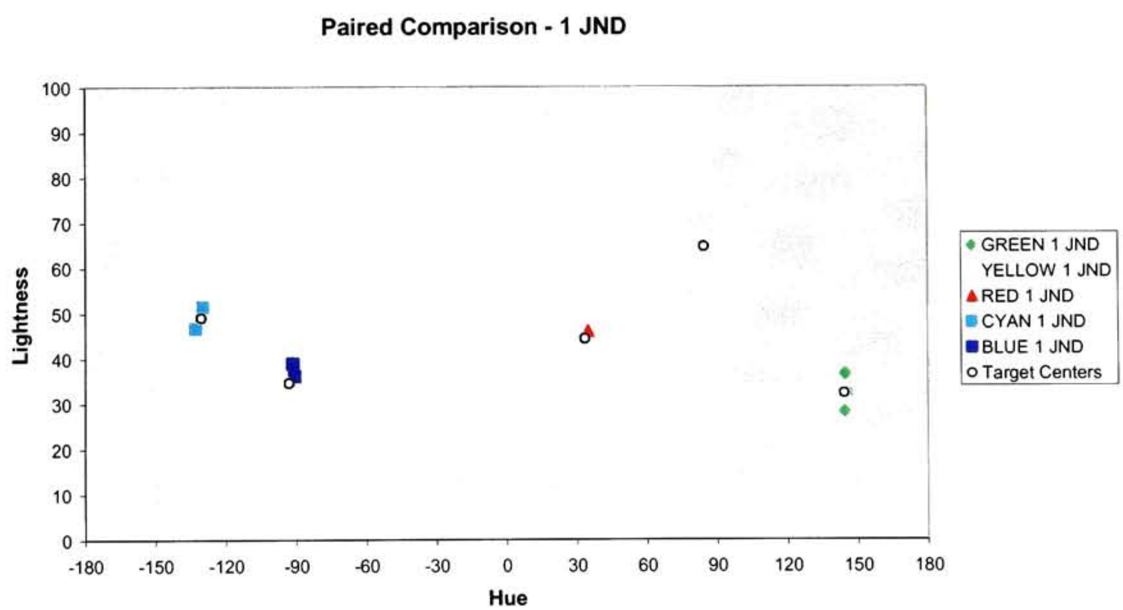


Figure 6.4: Paired Comparison Lightness vs. Hue 1 JND Discrimination Limit

In Figure 6.4 above, we can see that patches in 1 JND vary only in lightness with only a slight variation in hue, if any at all. In the graph below, Figure 6.5, we can see that there is still only a slight variation in hue axis (more than the 1 JND data) with most of the variation in the lightness axis.

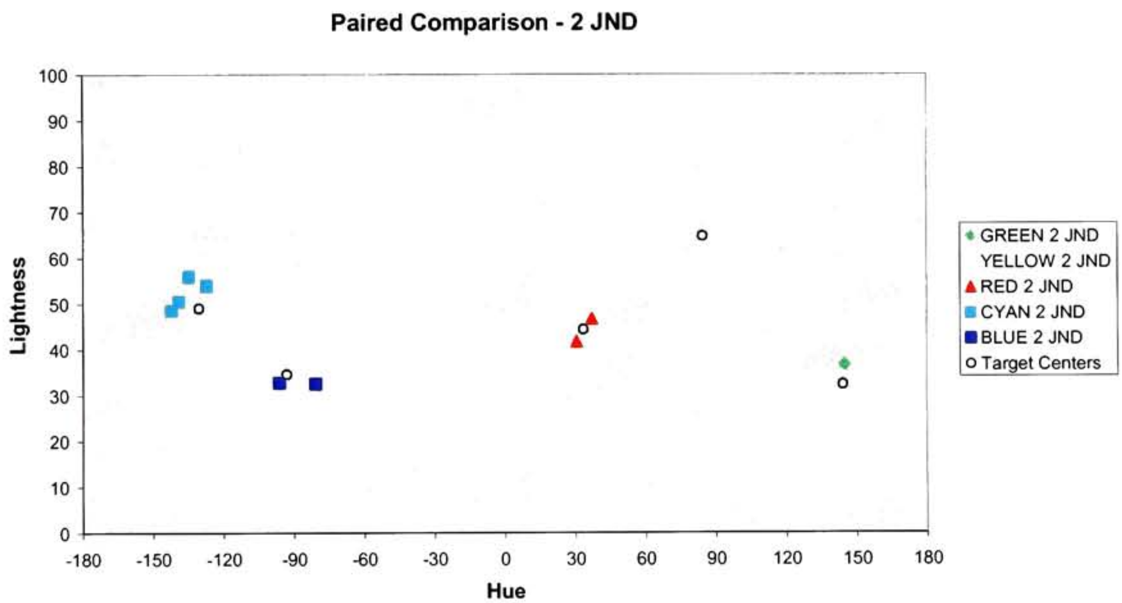


Figure 6.5: Paired Comparison Lightness vs. Hue 2 JND Discrimination Limit

Figure 6.6 on the next page, illustrates that a larger change in hue creates a more noticeable difference. Notice that now the patches vary much more in hue and with still variation in lightness.

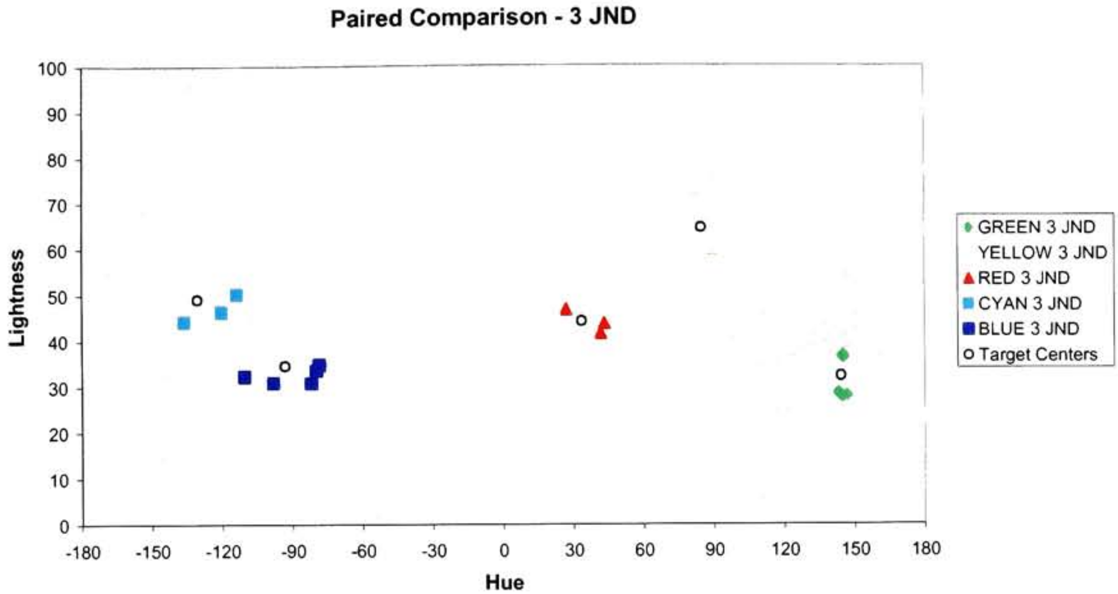


Figure 6.6: Paired Comparison Lightness vs. Hue 3 JND Discrimination Limit

Paired Comparison Comments

The discrimination limits for the paired comparison experiment are shown in Figures 6.1-6.6. As can be seen in the graphs, the smallest discrimination tolerance is in the hue direction. The major axes contributing to the largest discrimination tolerance were lightness and chroma.

The sampling for hue, chroma, and lightness were uniformly distributed in each dimension. Therefore, a chart with tolerance plotted as a function of the cumulative probability (z-score) will yield a measure of the discriminability tolerance. Additionally, a small CIE Delta E error at the one JND tolerance boundary along with a small cumulative probability indicates the judgment system is very sensitive to small colorimetric errors. This illustrates that almost all the samples made for the study were not a suitable match to the "logo" color.

Figure 6.7 below shows the average Delta E error as a function of the proportion of the samples which were within one, two, and three JND boundaries. Sixty-six percent of the samples are outside the 3 JND boundaries. Therefore, two thirds of our total sample grid would have been rejected by the standard print buying practice. Notice the one JND boundary is at approximately four Delta E level of error. This indicates that our subjects, on average, would have accepted samples as a match with a 4 delta E error or less. Print buying based on colorimetric measurements would have rejected all samples in our color patch test grid.

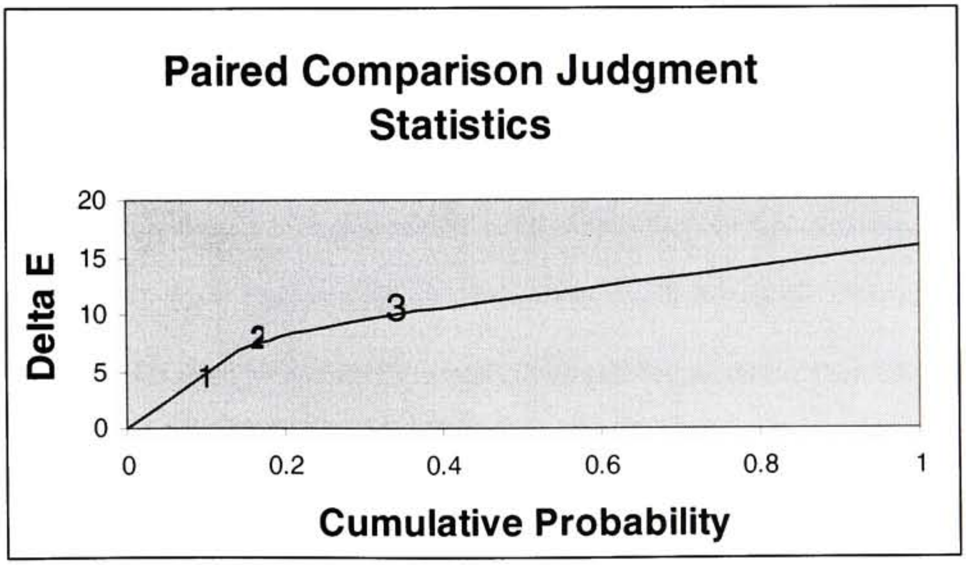


Figure 6.7: Paired Comparison CIE Delta E vs. Cumulative Probability of Not Matching the "Logo" Color

Memory Color Study

The results of the memory color scaling are shown on the next few graphs. The data for all graphs is displayed for all the "logo" colors as a function of hue. Each graph illustrates the boundary for discrimination limits of one, two, and three JND's. The ordinal axis is chosen to be hue for the reasons stated for the paired comparison study. The graphical data for the memory color study is presented in the same order as the paired comparison experiment. Figures 6.8 - 6.10 present the tolerances to chorma variation at the 1-3 JND tolerance boundaries. Figures 6.11-6.13 show the data for lightness tolerance bounds.

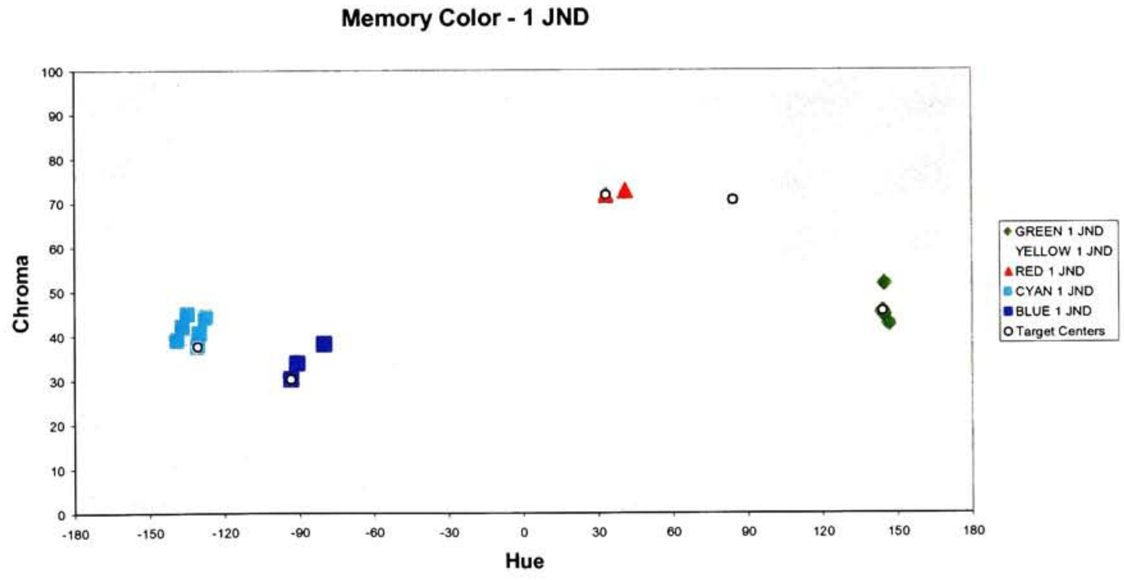


Figure 6.8: Memory Color Chroma vs. Hue 1 JND Discrimination Limit

Similar to the results from the paired comparison text, in Figure 6.8 above, we can see that patches in 1 JND vary only in chroma with only a slight variation in hue, if any at all. In the graph below, figure 6.9, we can see that there is still only a slight variation in hue axis (more than the 1 JND data) with most of the variation in the chroma axis for 2 JND.

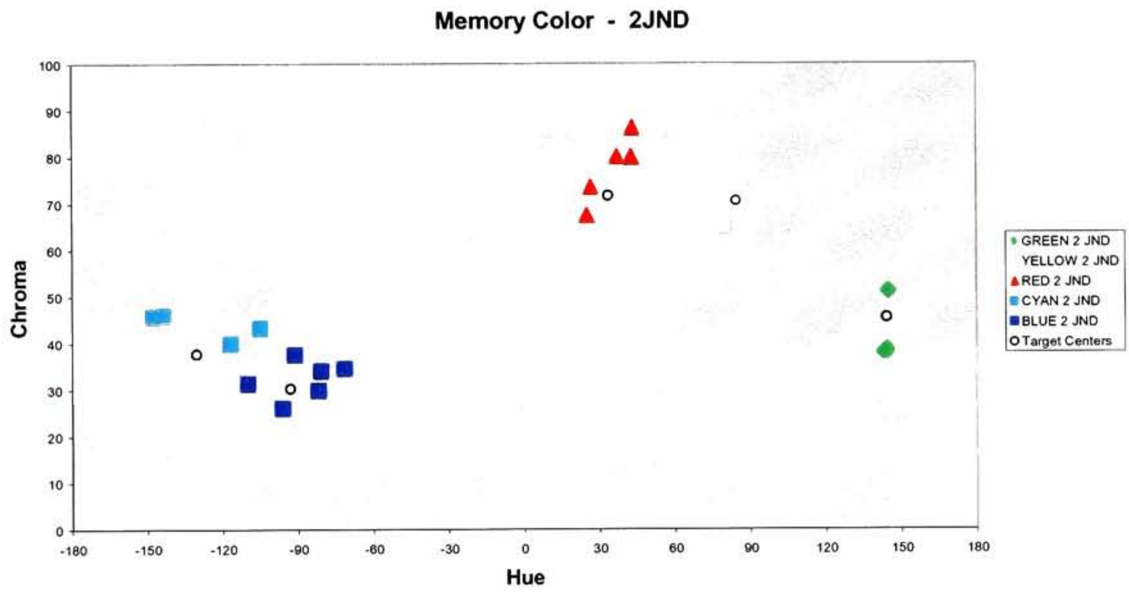


Figure 6.9: Memory Color Chroma vs. Hue 2 JND Discrimination Limit

Figure 6.10 on the next page, illustrates that a larger change in hue creates a more noticeable difference. Notice that now the patches vary much more in hue and with still variation in chroma.

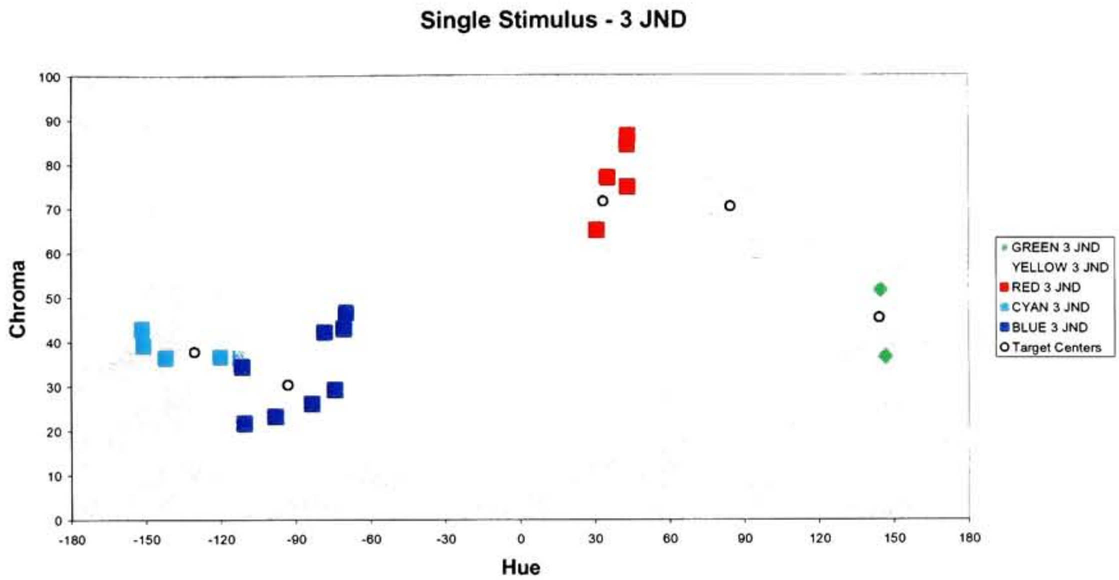


Figure 6.10: Memory Color Chroma vs. Hue 3 JND Discrimination Limit

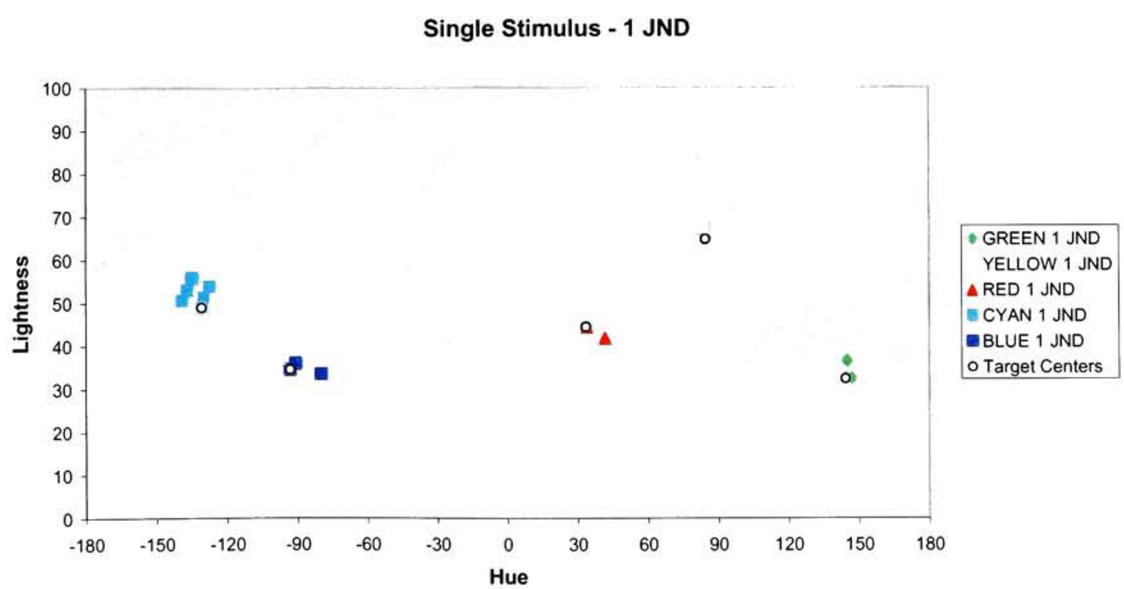


Figure 6.11: Memory Color Lightness vs. Hue 1 JND Discrimination Limit

Similar to the results from the paired comparison data, in figure 6.11 above, we can see that patches in 1 JND vary only in lightness with only a slight variation in hue, if any at all. In the graph below, figure 6.12, we can see that there is still only a slight variation in hue axis (more than the 1 JND data) with most of the variation in the lightness axis.

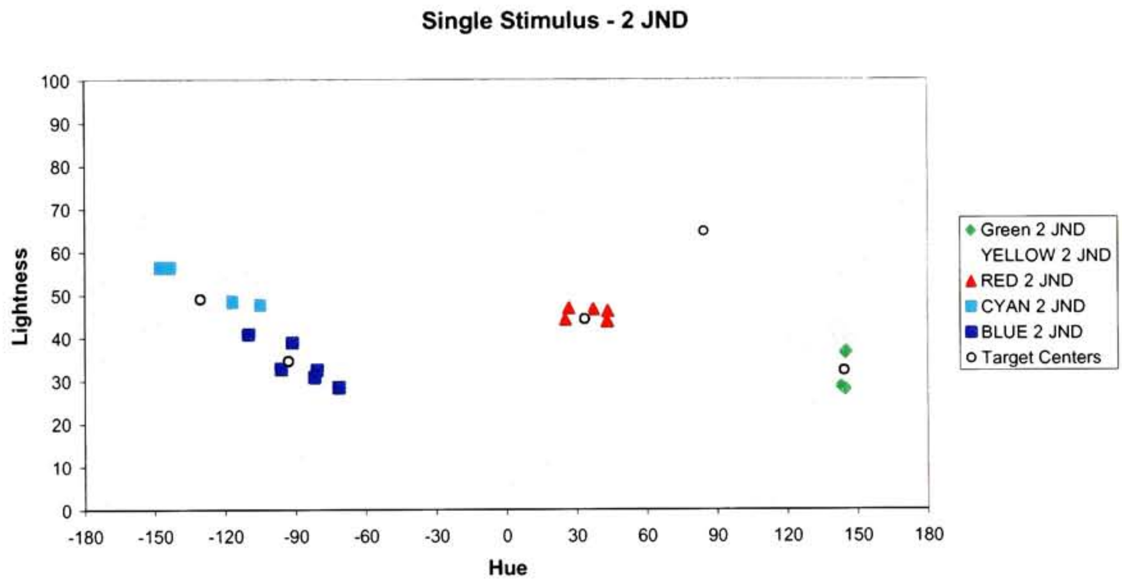


Figure 6.12: Memory Color Lightness vs. Hue 2 JND Discrimination Limit

Figure 6.13 on the next page, illustrates that a larger change in hue creates a more noticeable difference. Notice that now the patches vary much more in hue and with still variation in lightness.

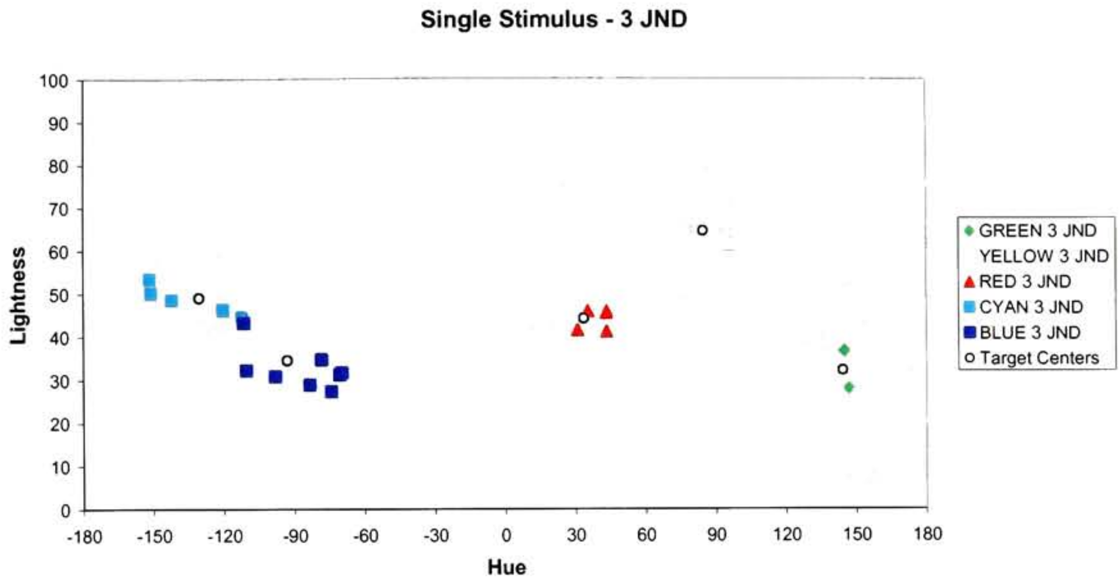


Figure 6.13: Memory Color Lightness vs. Hue 3 JND Discrimination Limit

Memory Color Study Comments

A comparative method is used to best analyze the above results. Figure 6.14 summarizes the memory color discrimination tolerance limits. When this data is compared to the data of the paired comparison study on Figure 6.15, we can see that nearly twice as many samples are accepted from memory color as accepted in paired comparison. The paired comparison experiment found that only 34% of the samples were considered matches at the 3 JND level. The memory color experiment shows that 57% of the samples were acceptable matches. This is a near doubling of the tolerance limit.

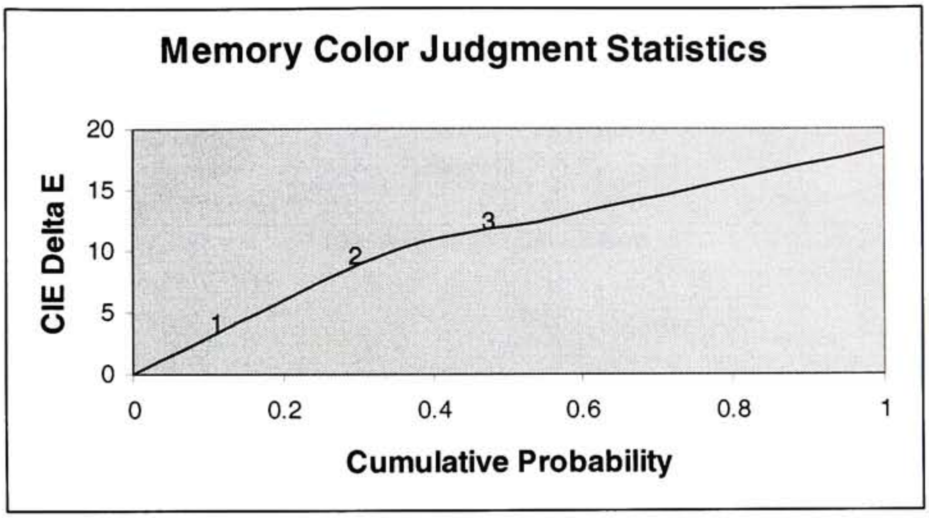


Figure 6.14: Memory Color CIE Delta E vs. Cumulative Probability of Not Matching the "Logo" Color

The tolerance limits for both conditions are cross-plotted for each "logo" color on Figure 6.15 below. Plotted in this manner, it is much easier to see the acceptance of the "logo" color has nearly twice the range for memory color as compared to paired comparison (a slope with a ratio of nearly 2:1).

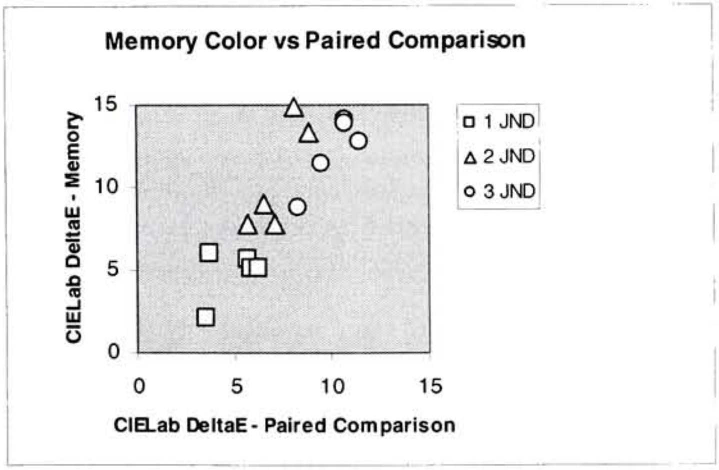


Figure 6.15: Memory Color Delta E vs. Paired Comparison Delta E

Chapter 7

Summary and Conclusion

The purpose of this study was to examine if the print buying practices of judging brand color (paired comparison) was an accurate representation of the way end users or consumers judge brand color in the market place (color memory). The first hypothesis stated the tolerance for color memory color matching of brand colors used by the average end user is larger than the paired comparison color match used by the print buyer. The second hypothesis stated the tolerance for color memory color matching is equal to or smaller than the paired comparison color matching of brand colors used by the print buyer.

Hypothesis: Tolerance is larger

According to the results, we learned that the tolerance limits for a consumer using color memory color matching are much larger than that of the paired comparison method. When examining which dimension of color had the least amount of influence on a decision we found that chroma (saturation) and or lightness of the "logo" reproduction had less importance.

Hypothesis: Tolerance is equal to or smaller

According to our study, the second hypothesis of the tolerance for color memory color matching is equal to or smaller than the paired comparison color matching of brand color which is used by print buyers is false. There was no evidence which found using color memory matching to have a tighter acceptance tolerance. However, our results showed us that the most important dimension in logo reproduction is the maintenance of hue for that color.

Benefits of the Study

The results of this research are beneficial to the printing and print buying industry. The findings imply that there is a large amount of money to be saved by re-examining the color buying practice. Currently there are no standards for color buying and these results help show standards are necessary and would be very cost effective. Additionally, no matter which method is used we have found that the most important color dimension in logo reproduction is the maintenance of hue and less important is saturation and lightness.

Recommendations for Further Study:

Recommendations for further study include: more "logo" colors, actual logo colors (4 color vs. special color), an increased number of observers, and a survey on color matching standards. It is recommended that this experiment be repeated for more "logo" colors, possibly actual logo colors with varying color dimensions (4 color and special colors), and using more observers (40 or more). Further more it is recommended to survey current color matching methods in use by print buyers to create a color matching standard.

Bibliography

Bibliography

Box, George E.P., Hunter, J.S., & Hunter, W.G. (1978). *Statistics For Experimenters: An Introduction to Design, Data Analysis, and Model Building.* New York, New York: John Wiley & Sons, 255 – 258.

Gescheider, George A. (1985). *Psychophysics: Method, Theory, and Application 2nd Edition.* Hillsdale, New Jersey: Lawrence Erlbaum Associates, Publishers, 1, 12, 42-43, 116-119.

Judd, Deane B., & Wyszecki, Gunter (1975). *Color in Business, Science, and Industry 3rd Edition.* New York, New York: John Wiley & Sons, 32-35, 342.

Barco, L.J., Hita, E.I., & Romero, J. (1986). *A Comparative Study of Successive and Simultaneous Methods in Color discrimination.* Vision Research, 26(3), 471-476.

Burnham, R.W., Clark, J.R., & Newhall, S.M. (1957). *Comparison of Successive with Simultaneous Color Matching.* Journal of the Optical Society of America, 47, 43-56.

Capilla, P., Carpinelli, J.P, Fez, M.D., Lunque, M.J., & Pozo, J.C. (2001). *Asymmetric Colour Matching: Memory Matching Versus Simultaneous Matching.* Color Research and Application, 26(6), 458-468.

Baldovi, R., Castro, Jose, Fez, M.D., & Perez-Carpinelli, J.P. (1998). *Color Memory Matching: Time Effect and Other Factors.* Color Research and Application, 23(4) 234-247.

Appendix

Appendix A

Original Data

Color: Green

Patch ID	X	Y	Z	L	a	b	Saturation	Delta E	Hue	Z score
1a	2.45	3.94	2.09	23.47	-22.41	14.49	26.69	20.83	147.12	-2.33
1b	3.07	5.48	2.37	28.06	-30.66	20.11	36.66	9.94	146.73	1.28
1c	3.93	7.26	2.96	32.39	-35.66	23.28	42.59	3.52	146.86	0.00
1d	4.84	9.37	3.19	36.69	-41.74	29.17	50.92	7.03	145.05	0.84
1e	5.79	11.7	3.77	40.74	-47.78	32.62	57.85	15.03	145.68	-2.33
2a	2.26	3.77	1.71	22.90	-23.85	16.96	29.27	18.74	144.58	-2.33
2b	2.96	5.39	2.04	27.82	-31.54	22.42	38.69	8.14	144.60	0.84
2c	3.86	7.23	2.6	32.32	-36.40	25.71	44.57	1.00	144.77	0.25
2d	4.79	9.33	3.17	36.61	-42.06	29.17	51.18	7.20	145.26	0.84
2e	6.07	12.1	3.88	41.42	-47.62	33.17	58.03	15.54	145.14	-2.33
3a	2.27	3.78	1.68	22.93	-23.79	17.32	29.43	18.59	143.95	-2.33
3b	3.08	5.51	2.15	28.14	-30.83	22.03	37.89	8.65	144.45	0.84
3c	3.82	7.22	2.48	32.30	-36.90	26.57	45.48	0.00	144.24	0.25
3d	4.75	9.23	3.04	36.42	-41.76	29.70	51.24	7.09	144.58	0.84
3e	6.18	12.2	4.04	41.56	-47.03	32.52	57.18	14.96	145.33	-2.33
4a	2.32	3.79	1.63	22.96	-22.89	17.88	29.04	18.95	142.01	-2.33
4b	3.03	5.48	2.07	28.06	-31.35	22.57	38.63	8.05	144.24	0.84
4c	3.87	7.27	2.53	32.41	-36.64	26.39	45.15	0.34	144.24	0.52
4d	4.71	9.23	3.05	36.42	-42.28	29.63	51.63	7.43	144.98	0.52
4e	5.85	11.8	3.73	40.93	-47.94	33.18	58.30	15.49	145.31	-2.33
5a	2.31	3.76	1.58	22.86	-22.65	18.21	29.06	19.03	141.21	-2.33
5b	3.24	5.7	2.14	28.64	-30.28	22.98	38.01	8.38	142.80	0.84
5c	3.86	7.23	2.51	32.32	-36.40	26.38	44.96	0.53	144.07	0.25
5d	4.82	9.4	3.1	36.74	-42.24	29.85	51.72	7.68	144.75	1.28
5e	6.07	12.1	3.73	41.44	-47.69	34.06	58.60	15.99	144.46	-2.33

Color: Red

Patch ID	X	Y	Z	L	a	b	Saturation	Delta E	Hue	Z score
1a	17.62	10.42	1.53	38.59	49.86	45.84	67.73	13.09	42.59	-2.33
1b	20.87	12.04	1.48	41.28	54.80	51.02	74.87	12.88	42.95	1.28
1c	24.06	13.73	1.58	43.84	58.40	54.38	79.80	14.91	42.96	0.84
1d	26.65	14.93	1.62	45.54	62.06	56.90	84.20	17.54	42.51	-2.33
1e	27.39	15.23	1.5	45.95	63.30	58.85	86.43	19.69	42.91	1.28
2a	17.89	10.52	2.28	38.76	50.56	39.27	64.02	10.79	37.84	-2.33
2b	21.18	12.3	1.86	41.69	54.52	47.94	72.60	10.26	41.33	0.52
2c	24.04	13.65	1.57	43.73	58.81	54.29	80.04	14.79	42.71	0.84
2d	26.65	14.95	1.59	45.57	61.94	57.25	84.35	17.88	42.75	1.28
2e	27.56	15.4	1.53	46.18	62.99	58.93	86.26	19.73	43.09	0.84
3a	18.11	10.53	4.17	38.78	51.65	27.01	58.29	15.94	27.61	-2.33
3b	21.44	12.25	3.94	41.61	56.10	33.16	65.16	7.86	30.59	1.28
3c	24.88	14.08	3.65	44.35	59.78	39.54	71.68	0.00	33.48	0.25
3d	27.38	15.26	3.37	45.99	63.08	44.07	76.95	5.84	34.94	1.28
3e	28.29	15.74	2.91	46.63	63.93	48.17	80.05	9.84	37.00	0.84
4a	18.39	10.57	5.58	38.85	52.83	20.26	56.58	21.23	20.98	-2.33
4b	21.79	12.29	5.74	41.67	57.47	24.43	62.45	15.52	23.03	-2.33
4c	25.06	13.99	5.81	44.22	61.11	28.51	67.43	11.11	25.01	0.84
4d	28.09	15.46	5.99	46.26	64.75	31.26	71.90	9.85	25.77	-2.33
4e	29.01	15.92	5.86	46.87	65.71	32.87	73.47	9.28	26.57	0.84
5a	18.29	10.44	7.39	38.62	53.28	12.57	54.74	28.33	13.28	-2.33
5b	22.05	12.39	7.85	41.83	58.01	16.44	60.30	23.30	15.83	-2.33
5c	25.73	14.2	8.7	44.52	62.65	18.18	65.23	21.56	16.18	-2.33
5d	28.66	15.56	9.15	46.39	66.41	19.95	69.34	20.79	16.72	-2.33
5e	30	16.13	9.63	47.14	68.31	19.74	71.11	21.75	16.12	-2.33

Color: Blue

Patch ID	X	Y	Z	L	a	b	Saturation	Delta E	Hue	Z score
1a	5.64	5.24	14.87	27.41	7.95	-28.18	29.28	12.17	-74.24	1.28
1b	6.33	5.64	17.88	28.49	10.96	-32.85	34.63	14.23	-71.55	0.84
1c	6.98	6.07	21.19	29.59	12.92	-37.33	39.50	16.92	-70.91	-2.33
1d	7.91	6.8	24.82	31.35	14.25	-40.57	43.00	19.19	-70.65	1.28
1e	8.33	7	27.27	31.81	16.07	-43.67	46.54	22.36	-69.80	1.28
2a	5.79	5.82	15.05	28.95	3.00	-25.93	26.10	8.51	-83.40	1.28
2b	6.63	6.56	18.2	30.78	4.20	-29.54	29.84	7.01	-81.90	0.84
2c	7.5	7.31	21.93	32.50	5.43	-33.64	34.08	8.09	-80.83	0.84
2d	8.15	7.81	25.39	33.58	6.80	-37.64	38.25	11.22	-79.77	0.52
2e	8.93	8.39	29.12	34.78	8.45	-41.33	42.19	14.95	-78.44	1.28
3a	5.97	6.6	15.24	30.88	-3.28	-23.04	23.27	8.32	-98.09	1.28
3b	6.77	7.42	18.08	32.74	-2.81	-25.91	26.07	4.91	-96.19	0.84
3c	7.72	8.31	22.1	34.62	-1.62	-30.29	30.33	0.00	-93.06	0.00
3d	8.55	9.04	25.72	36.06	-0.33	-33.90	33.91	4.10	-90.56	0.25
3e	9.96	10.6	31.39	38.90	-0.86	-37.50	37.51	8.42	-91.32	0.84
4a	6.13	7.21	15.09	32.28	-7.56	-20.28	21.65	11.87	-110.44	1.28
4b	7.16	8.63	18.38	35.26	-9.75	-22.18	24.23	11.51	-113.74	-2.33
4c	8.38	10.3	22.61	38.39	-11.88	-24.68	27.39	12.28	-115.70	-2.33
4d	9.75	11.7	28.13	40.80	-10.73	-29.48	31.37	11.04	-110.00	0.84
4e	10.9	13.3	32.85	43.24	-12.54	-32.03	34.40	14.02	-111.38	1.28
5a	6.47	8.39	15.27	34.78	-14.70	-16.38	22.01	19.10	-131.91	-2.33
5b	7.7	10.2	19.08	38.20	-17.23	-18.50	25.28	19.89	-132.97	-2.33
5c	8.91	11.9	23.26	41.07	-18.83	-21.19	28.35	20.51	-131.63	-2.33
5d	10.2	13.8	27.94	43.94	-20.74	-23.77	31.55	22.25	-131.10	-2.33
5e	11.4	15.5	33.21	46.24	-21.82	-27.34	34.98	23.49	-128.59	-2.33

Color: Yellow

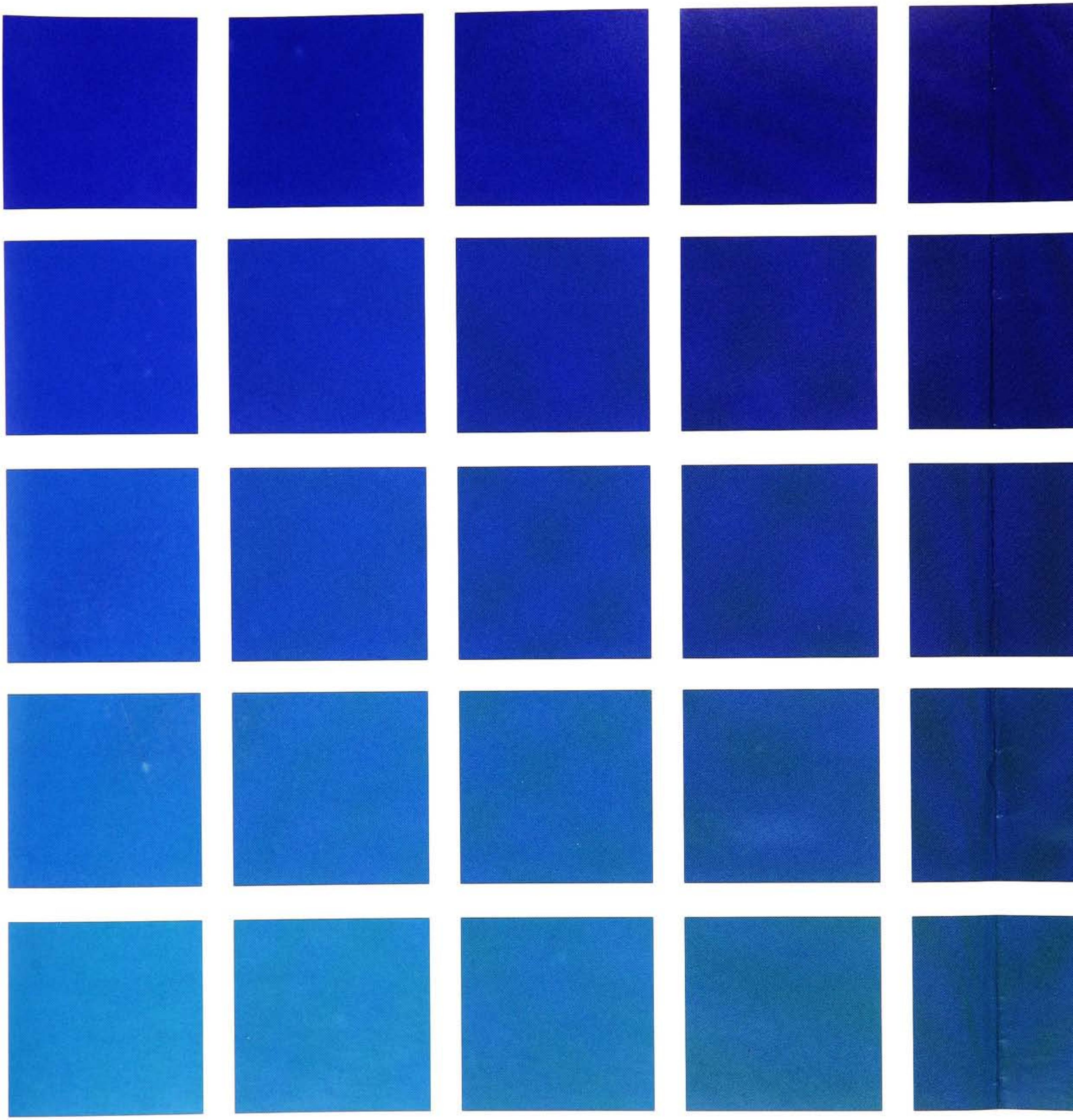
Patch ID	X	Y	X	L	a	b	Saturation	Delta E	Hue	Z score
1a	28.33	33.14	5.11	64.27	-11.96	66.24	67.31	19.18	100.23	-2.33
1b	33.59	38.38	5.29	68.30	-9.80	72.35	73.01	17.12	97.71	-2.33
1c	33.57	38.4	5.39	68.31	-9.93	71.92	72.60	17.20	97.86	1.28
1d	40.03	44.98	5.58	72.88	-8.25	78.93	79.36	19.21	95.97	1.28
1e	46.25	52.15	6.06	77.37	-9.12	84.60	85.09	24.91	96.15	-2.33
2a	23.77	26.31	4.22	58.33	-5.32	60.46	60.69	16.83	95.03	1.28
2b	29.06	31.66	4.64	63.06	-3.89	66.44	66.55	11.46	93.35	1.28
2c	33.8	36.33	4.82	66.77	-2.48	71.94	71.98	9.66	91.97	0.84
2d	39.78	41.71	5.1	70.67	0.49	77.32	77.32	11.21	89.64	-2.33
2e	44.51	46.71	5.49	74.00	0.39	81.27	81.27	15.79	89.72	-2.33
3a	23.99	25	3.93	57.08	1.06	59.88	59.89	14.09	88.99	-2.33
3b	28.76	29.36	4.22	61.10	3.41	65.23	65.32	7.04	87.01	-2.33
3c	33.93	33.7	4.46	64.72	6.80	70.22	70.55	0.00	84.47	0.84
3d	38.04	37.26	4.49	67.47	8.74	74.80	75.31	5.68	83.34	0.52
3e	42.56	41.28	4.62	70.37	10.29	79.14	79.81	11.12	82.59	0.84
4a	24.49	23.71	3.63	55.80	8.75	59.40	60.04	14.16	81.62	-2.33
4b	28.46	26.73	3.72	58.72	12.48	63.92	65.13	10.38	78.96	0.84
4c	33.59	30.99	3.96	62.50	15.20	69.06	70.72	8.77	77.59	1.28
4d	37.2	33.78	4.07	64.79	17.58	72.40	74.50	10.99	76.35	1.28
4e	40.71	36.45	4.21	66.86	19.80	75.22	77.78	14.08	75.26	-2.33
5a	24.11	21.42	3.29	53.41	17.40	57.36	59.94	20.14	73.12	-2.33
5b	28.39	24.73	3.38	56.81	20.44	62.66	65.91	17.48	71.93	-2.33
5c	31.99	27.41	3.45	59.35	23.06	66.61	70.49	17.50	70.90	-2.33
5d	36.1	30.11	3.54	61.75	27.03	70.20	75.23	20.45	68.94	-2.33
5e	37.85	31.33	3.52	62.79	28.33	72.11	77.47	21.69	68.55	-2.33

Color: Cyan

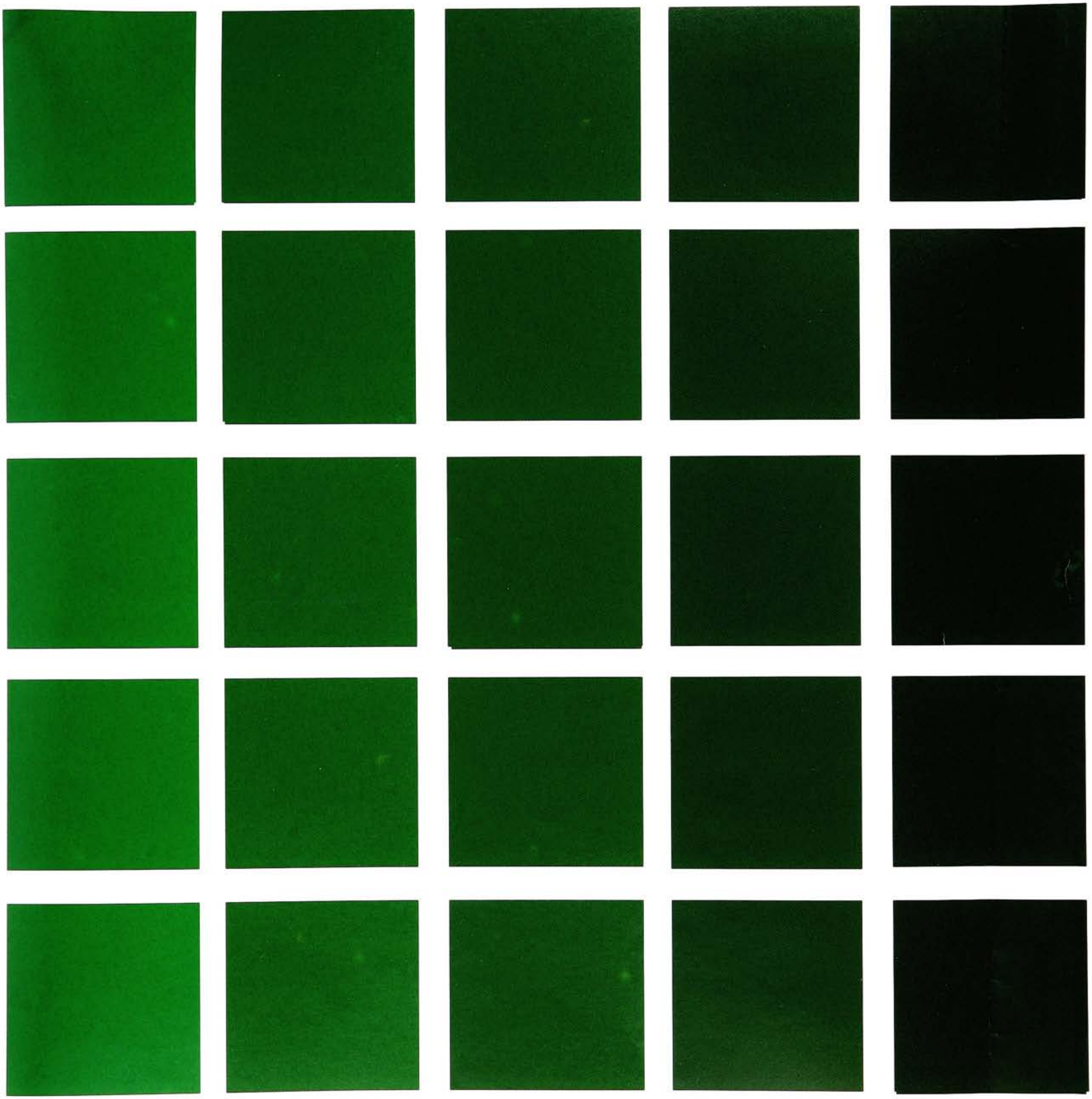
Patch ID	X	Y	Z	L	a	b	Saturation	Delta E	Hue	Z score
1a	9.32	11.45	27.02	40.33	-12.19	-28.60	31.09	15.08	-113.09	-2.33
1b	10.21	12.6	31.07	42.15	-12.94	-31.44	34.00	13.72	-112.38	-2.33
1c	11.57	14.33	36.09	44.70	-13.81	-33.79	36.50	12.59	-112.23	1.28
1d	12.59	15.31	41.37	46.06	-12.56	-37.90	39.93	15.34	-108.34	-2.33
1e	13.86	16.53	47.37	47.66	-11.19	-41.82	43.29	18.71	-104.98	0.84
2a	9.68	12.52	27.44	42.03	-16.60	-26.31	31.11	10.83	-122.25	-2.33
2b	10.96	14.19	32.21	44.50	-17.39	-28.98	33.79	8.43	-120.96	-2.33
2c	11.92	15.53	36.64	46.35	-18.44	-31.64	36.63	7.23	-120.23	1.28
2d	13.33	17.15	42.96	48.45	-17.98	-35.61	39.89	9.49	-116.79	0.84
2e	14.69	18.63	49.23	50.25	-17.20	-39.32	42.91	12.91	-113.62	-2.33
3a	10.03	13.95	27.08	44.16	-23.00	-22.08	31.88	8.39	-136.17	-2.33
3b	11.33	15.74	32.74	46.63	-23.85	-26.04	35.31	3.68	-132.49	-2.33
3c	12.75	17.65	38.05	49.07	-24.47	-28.72	37.73	0.00	-130.43	0.25
3d	14.06	19.6	43.74	51.38	-25.96	-31.43	40.77	3.86	-129.55	0.00
3e	15.83	21.99	51.63	54.02	-26.65	-35.28	44.22	8.50	-127.07	0.25
4a	10.32	14.9	27.45	45.50	-26.50	-20.35	33.41	9.33	-142.48	-2.33
4b	11.82	17.25	32.58	48.57	-28.72	-22.47	36.47	7.57	-141.96	1.28
4c	13	18.92	37.75	50.59	-29.38	-25.72	39.05	5.95	-138.80	0.52
4d	14.44	21.06	44.08	53.02	-30.64	-29.00	42.19	7.33	-136.57	0.25
4e	16.42	23.86	51.79	55.95	-31.60	-32.11	45.05	10.47	-134.54	0.25
5a	10.88	16.68	27.9	47.85	-32.42	-16.97	36.59	14.24	-152.37	-2.33
5b	12.02	18.58	32.15	50.19	-34.30	-19.09	39.25	13.80	-150.90	1.28
5c	13.58	21.43	37.47	53.42	-37.78	-20.50	42.98	16.23	-151.51	1.28
5d	15.54	24.33	45.33	56.42	-38.69	-24.52	45.81	16.55	-147.64	0.84
5e	15.8	24.3	47.99	56.39	-37.05	-27.44	46.10	14.60	-143.47	0.84

Appendix B

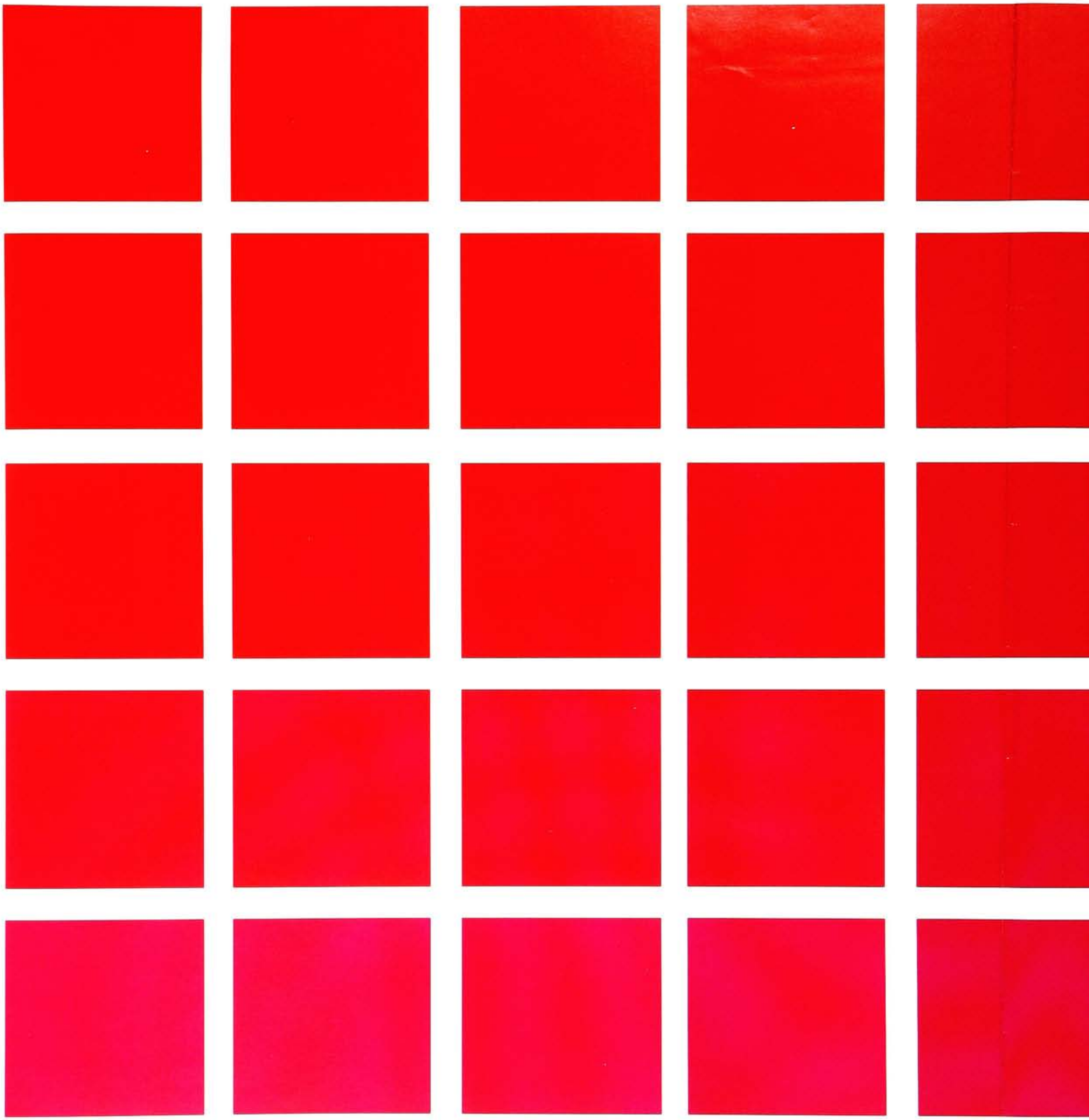
Test Color Patches



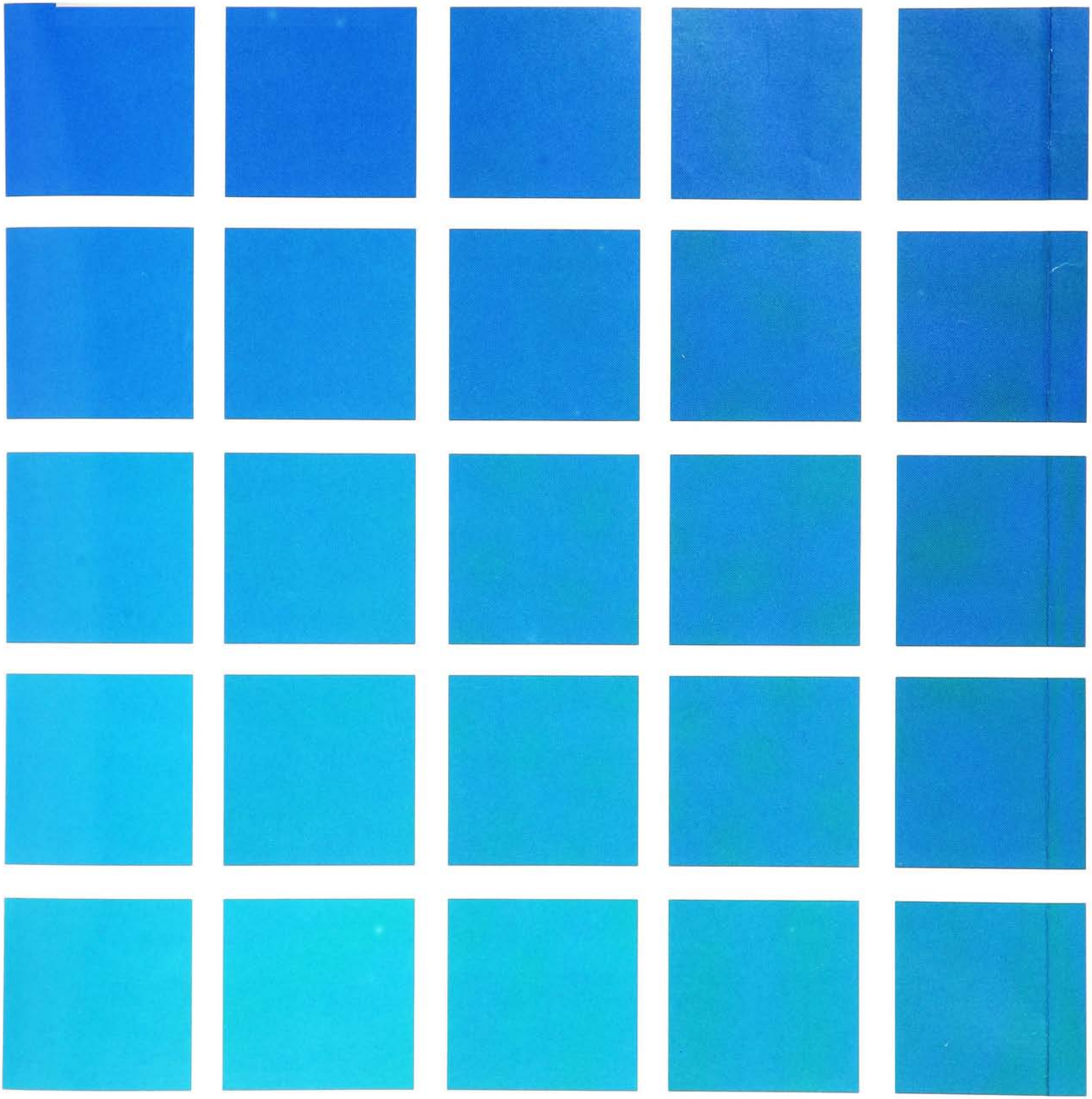
Allison Santoro
4/23/03
CMYK eps from Photoshop
brandcolor_blue_cmyk



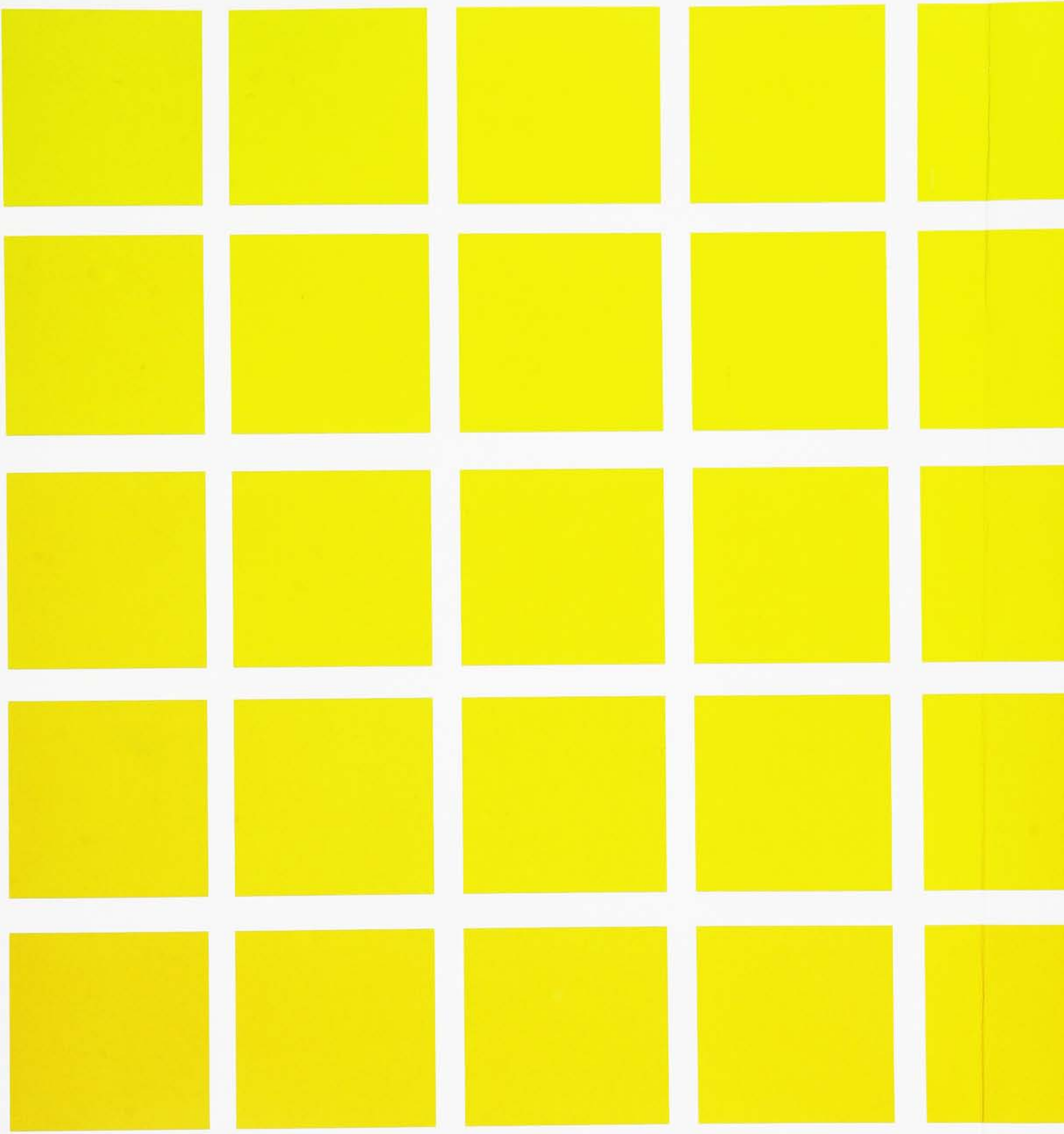
Allison Santoro
4/23/03
CMYK eps from Photoshop
brandcolor_green_cmyk



Allison Santoro
4/23/03
CMYK eps from Photoshop
brandcolor_red_cmyk



Allison Santoro
4/23/03
CMYK EPS file from Photoshop



Yellow test B 8/14/03

Appendix C

Oral Presentation

Brand Color Tolerances

A comparison of color matching:
Memory Color vs. Paired Comparison

Presentation Overview:

- Purpose of Study
- Hypothesis
- Subjective Testing
- Results
- Summary
- Conclusion
- Recommendations

Purpose of Study:

- Are the print buying practices of judging color an accurate representation of the way end users judge color in the market place?
- To examine current practices in color matching by a print buyer. Are these practices wasteful or necessary?
  - Print Buyer = Final Proof + Press Sheet
- To examine the current practices in color matching used by the consumer or end user
  - End user = Color Memory + Object in Hand
- To understand if the end user's method is as good as the print buyer's method
- In order to understand we must examine the tolerances for each method

Hypothesis

- The tolerance for color memory color matching used by the end user is larger than that of a print buyer using the paired comparison method.
- The tolerance for color memory color matching used by the end user is equal to or smaller than that of a print buyer using the paired comparison method.

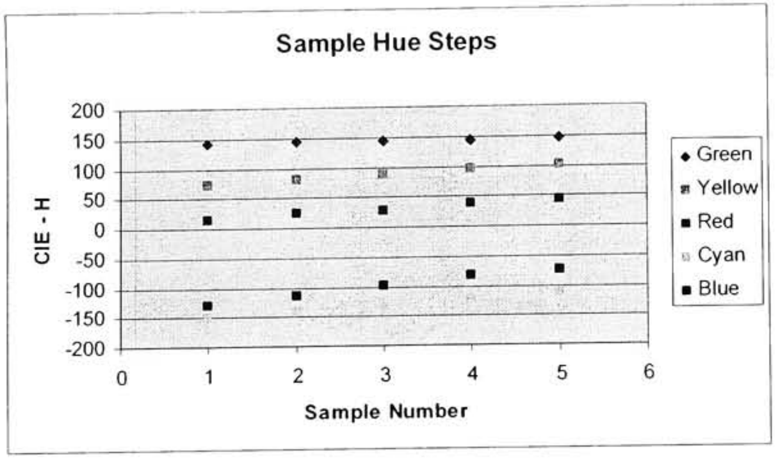
Subjective Testing:

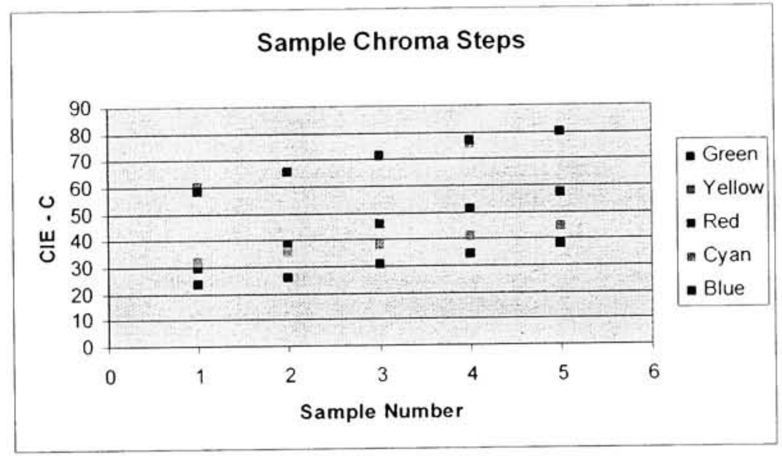
- Methodology
- Experimental Procedure
- Evaluating the Data

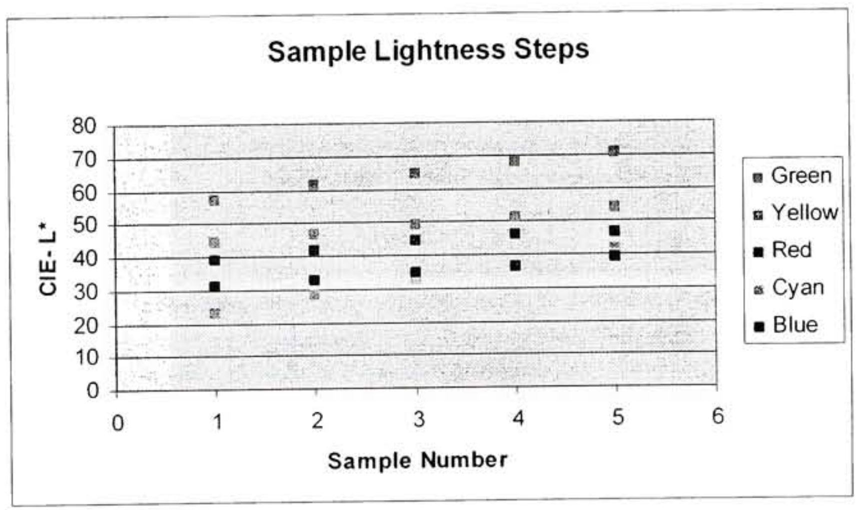
Methodology

- Created 5 “logo” colors from around the color spectrum (red, green, blue, yellow, cyan)
- For each of the 5 “logo” colors, created 25 colors varying in hue, saturation, and lightness.
- Selected 20 judges to take part in experiments
- Two test experiments: memory color vs. paired comparison

Distribution of Color Patches:







Experimental Procedures

Color Memory Experiment:

- Judge was asked to examine the “logo” color patch for about 1 minute (storing it in memory)
- After the “logo” color patch was taken away, judge did not look at any color patches for about 1 minute
- Next the judge was shown individually 25 color patches similar to the “logo” patch and asked if it was a match to the “logo” patch first shown
- Repeated for each of the 5 “logo” colors

Paired Comparison Experiment:

- Judge was given the “logo” color patch and allowed to keep it
- Next the judge was shown individually 25 color patches similar to the “logo” patch and asked if it was a match by comparing it to the “logo” patch
- Repeated for each of the 5 “logo” colors

Evaluating the Data

- Data was gathered for each of the 20 judges
- Color measurement data for each patch were taken (CIE Lab)
- Using data we found which patches were either 1, 2, or 3 JND (Just Noticeable Difference) from the "logo" colors (Thurston's Method)
  - Calculated z-score for each patch (# of standard deviations the patch is from the mean/"logo" color)
  - Set tolerance limits for z-score = the JND's
  - 1 JND = upper limit of 0.85 z-score, 2 JND = upper limit of 1.29 z-score, 3 JND = upper limit of 2.33 z-score

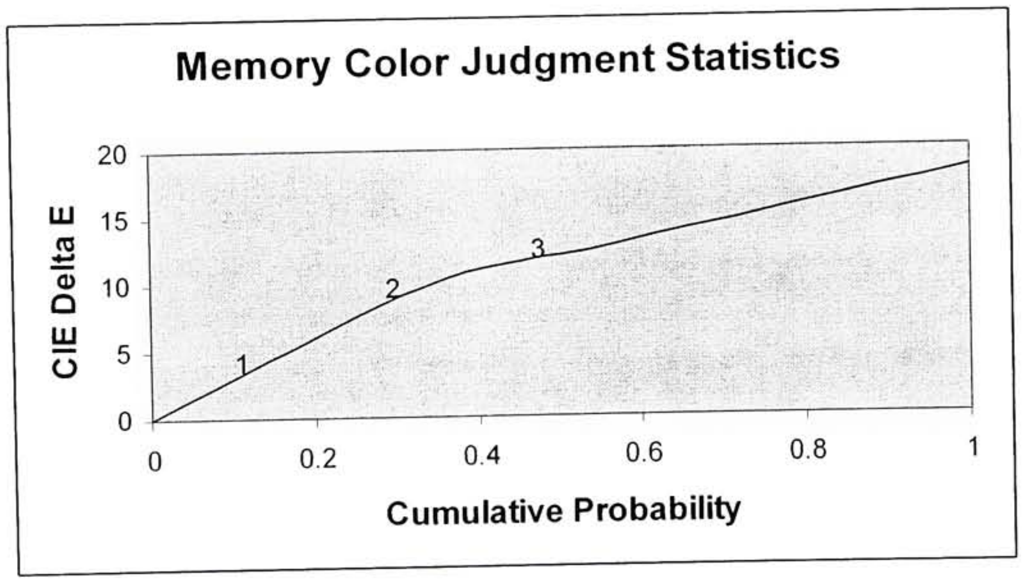
Results

- Color Memory Experiment
- Paired Comparison Experiment

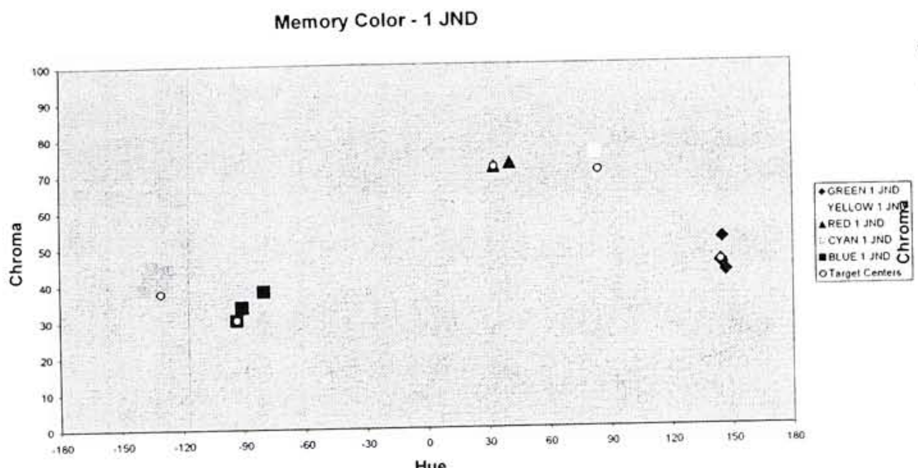
Results: Color Memory Experiment

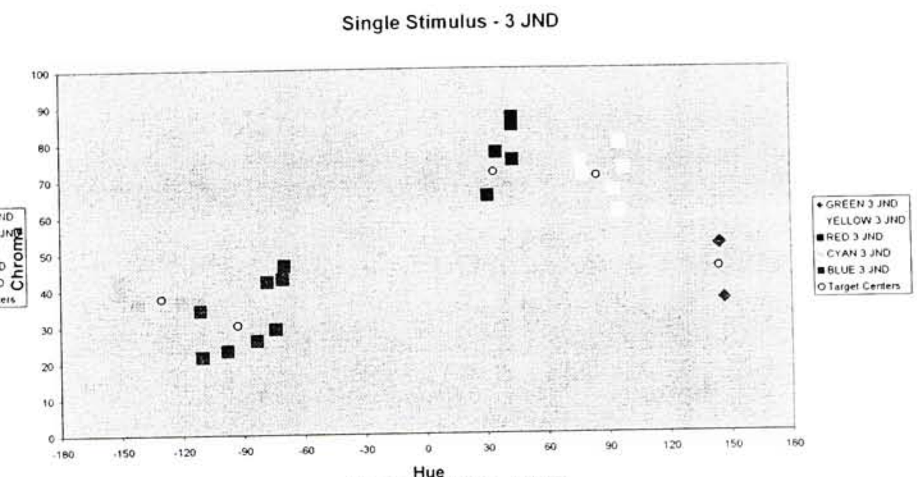
- Nearly twice as many color patches were accepted as a match as the paired comparison data
  - 34% found as a match in Paired Comparison compared to 57% in Color Memory
- Avg. Delta E = 4 for 1 JND, same for Paired Comparison, Delta E = 15 for 3 JND only 5 points higher than Paired Comparison
- Hue most critical factor, 2nd chroma, and least important is lightness in a color match

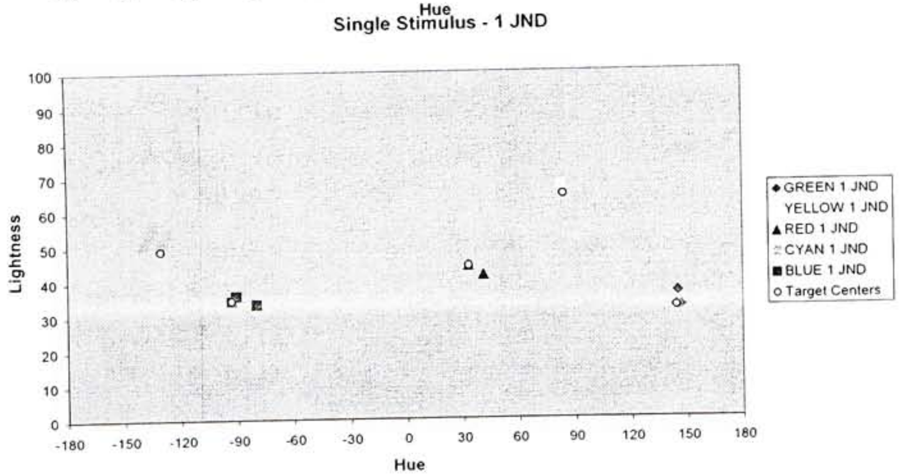
Twice as many patches accepted!

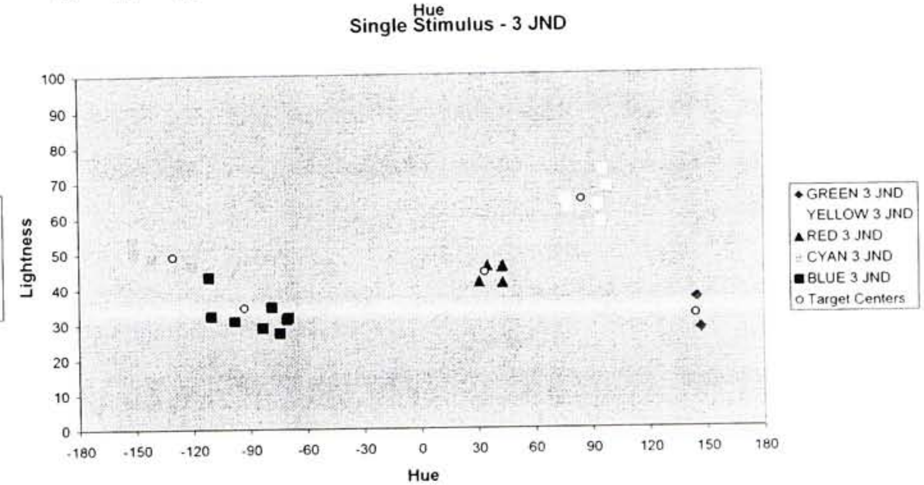


Hue most critical factor





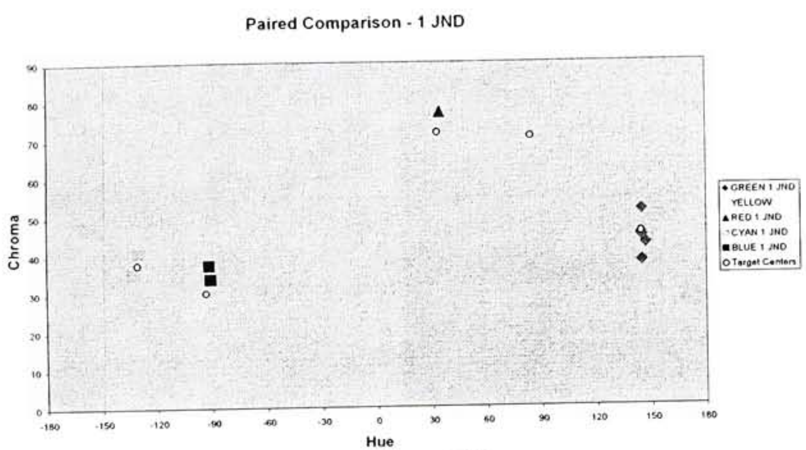


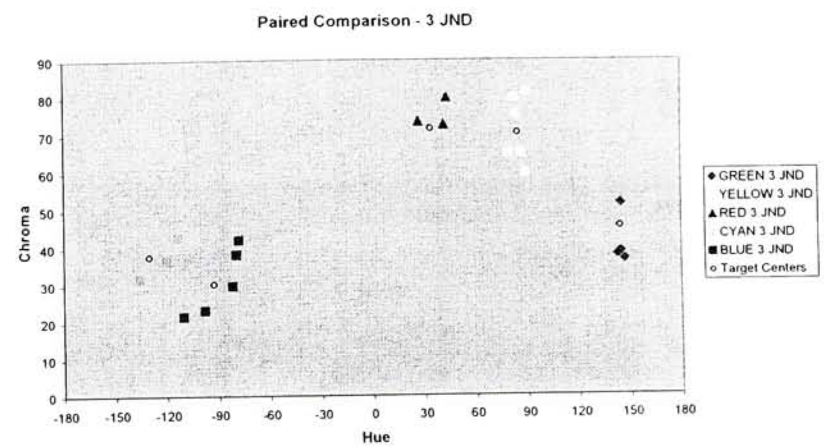


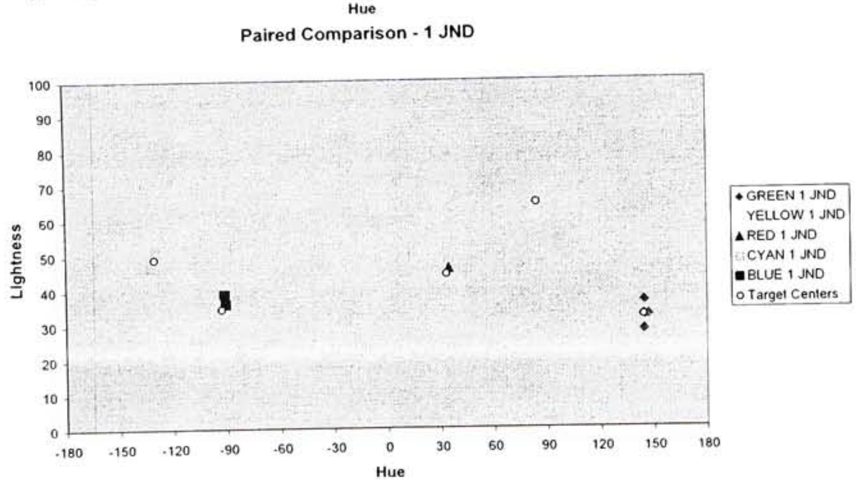
Results: Paired Comparison Experiment

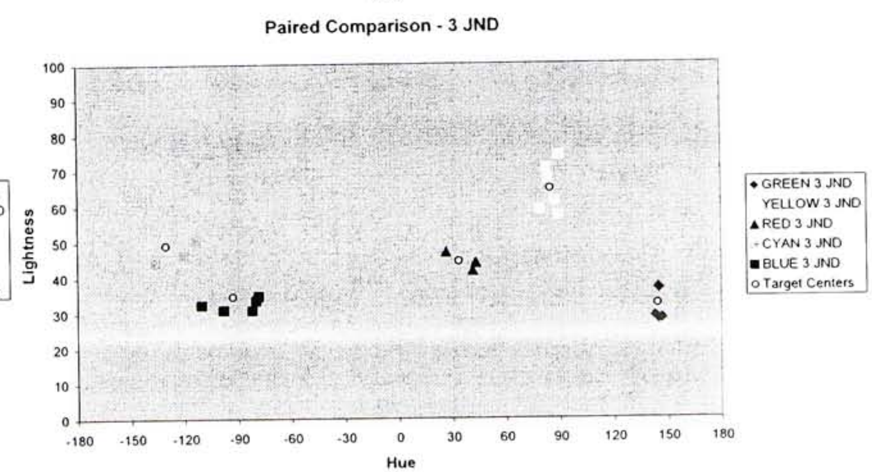
- Hue was most important factor in determining a match
- Chroma was the next critical factor in determining a match
- Lightness was the least critical factor in determining a match
- 66% of samples outside the 3 JND boundaries = 2/3 of our total sample grid would have been rejected
- 1 JND on averaged around a Delta E = 4, therefore, all patches would have been rejected using print buying standards

Hue most critical factor – again!

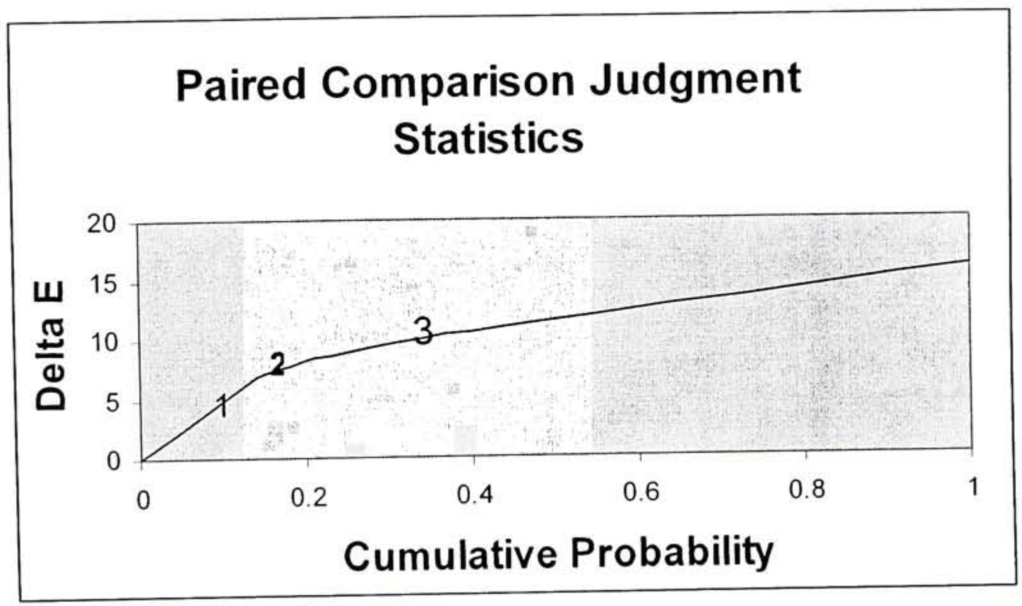








66% of samples outside of 3 JND!



Summary:

- Tolerance limits for an consumer using color memory color matching are much higher than that of the paired comparison method
- Most important color dimension for color matching is hue
- Least important color dimensions for color matching are chroma and lightness

Conclusion:

- Currently no standards for color buying which reflect the consumer experience
- Consumers method for judging color are far more lenient that that used by print buyers
- Most important color dimension in logo reproduction is the maintenance of hue.

Recommendations:

- Repeated experiments with: more “logo” colors and more observers/judges
- Study/Survey on color buying practices around the world for both print and packaging
- Development of color matching standards that more closely reflect the consumer’s experience